

PSYCHOGALVANIC RESPONSES
IN ARITHMETICAL WORK:

Effects of Experimental Changes
in Addition

BY
RICHARD SEARS, Ph. D.

ARCHIVES OF PSYCHOLOGY
R. S. WOODWORTH, EDITOR
No. 155

Submitted in partial fulfillment of the requirements
for the Degree of Doctor of Philosophy in
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CHAPTER I

INTRODUCTION

1. NATURE OF THE PROBLEM

The purpose of this experiment has been to determine to what extent the physiological changes measured by the psychogalvanic response (psychogalvanic reflex)¹ can be demonstrated to vary concomitantly with objectively measured and quantitatively varied changes in mental work.

A study of the literature had persuaded the writer that the psychogalvanic response, while it probably does not satisfactorily measure any of the conventionally named psychological functions such as emotion or conation, may measure—at least roughly—something important to psychology; namely, degree of hyper-functioning of the sympathetic (thoracic-lumbar) division of the autonomic nervous system.

The value of even a rough objective measure of sympathetic energy-expenditure during mental work will readily be appreciated. Thus far there have been only a few studies of the psychogalvanic response as related to mental work. All of these have been carried out with a very small number of subjects. Widely varying types of material have been used. Changes in the difficulty, complexity, or speed of performance of the mental work have not been objectively measured, and have been quantitatively varied only in a very indefinite fashion.

The writer has endeavored in the present experiment to meet as far as possible these hitherto unfulfilled conditions.

¹ Although it is generally agreed that the response usually called the "psychogalvanic reflex" is a sudden diminution of the apparent resistance of the skin to a small electric current, a number of writers (Aveling, Jeffress, Darrow, and others) have argued that the term is a misnomer, claiming that the response is not sufficiently localized to be termed a reflex. Moreover, the prefix "psycho" has been objected to on the grounds that the response is not necessarily associated with consciousness. These criticisms may be justified, and perhaps some such term as "galvanic skin response" would be better, but for the present it seems justifiable to follow common usage rather than to add to the confusing multiplicity of psychological terms. The writer has, however, substituted the term *response* for *reflex*.

2. TECHNIQUE OF PSYCHOGALVANIC EXPERIMENTS

The technique of psychogalvanic experimentation has been extremely variable, and quite controversial.

Importance of Constant Current. Of late years it has been agreed by most experimenters that for accurate work it is desirable to keep the current in the circuit constant during the experiment, regardless of the variations in apparent resistance of the subject or subjects. This problem was generally ignored by earlier investigators. Wechsler has given considerable evidence on this point (46, pp. 68-80). Prideaux (31) and Smith (36) have taken care either to maintain a constant current or to compensate for its lack by statistical procedures. Hathaway's (18) apparatus is designed to maintain a constant current. Davis (7, p. 32) writes as follows: "From the nature of the current reflex relation there must be drawn the practical conclusion that during any sort of exact experimental work on the reflex the measuring current should be controlled for physiological as well as physical reasons." Some new and carefully controlled experimental evidence in favor of this view is presented in Davis' article.

On the other hand, James and Thouless (19) reached conclusions diametrically opposed to the more generally accepted view. They believed that the p.g. phenomenon is wholly a function of the counter E.M.F. of polarization, and that the important thing to keep constant is not the current but the voltage. As their opinion has received no confirmation from other sources, the weight of expert judgment seems to rest heavily on the other side.

Types of Apparatus. Since the first psychogalvanic investigations there have been many important refinements of apparatus.

Vigorous (42), Veraguth (41), and a number of the earlier experimenters simply placed the subject in circuit with a shunted galvanometer and two Leclanché cells, of about 2.5 volts each. Féré (10, 11) and a large number of later investigators have placed a Wheatstone Bridge in the Vigorous-Veraguth circuit, the subject being the unknown resistance in one of the arms of the Bridge. This made it possible to measure the resistance of the subject and to bring the galvanometer needle back to a convenient zero point.

In 1920, Godefroy (13, 14) described a new method of measuring the phenomenon. He used the Veraguth circuit (with a higher voltage, c. 20 volts) into which he introduced an alternating current transformer. In Godefroy's procedure the subject is connected with the primary coil of the transformer, the secondary coil being connected directly with the galvanometer. After each deflection the galvanometer returns spontaneously to the zero point.

Methods of Compensating for Changes in Current. Hathaway (18) has devised an apparatus employing alternating current which is sensitive to very small changes in intensity, automatically keeps intensity constant for all subjects, and is free from polarization. Davis (27) reports an elaborate technique for using the Westinghouse (Osiso) Oscillograph in psychogalvanic experiments, with a new method for keeping the current constant.

Smith (36), using the Veraguth circuit with the addition of a Wheatstone Bridge, gives rather elaborate statistical justification for a method of compensating for changes in apparent resistance by multiplying each deflection by the subject's initial resistance. Another method he recommends for the same purpose is reduction of the individual deflections to percentages of the subject's mean deflection for the series of stimuli used in the experiment.

A common method of recording psychogalvanic changes, when a circuit without mechanical methods of controlling the current is used, has been to calculate the percentage change, or ratio of apparent ohmic change to initial bodily resistance. Using an apparatus patterned after that of Smith, Lauer (25) calculated reliability coefficients of 348 reactions of 23 subjects and found percentage change to be more reliable than deflections (on millimeter scale) with which, however, it correlated $+ 889 \pm .01$. He found no relation between size of deflections and initial resistance, the correlation being $-.092$.

That the methods recommended by Smith and Lauer are cumbersome and time consuming is obvious, and in any case they seem of more questionable validity than the use of direct means of keeping the current constant.

Wechsler (46) used a method of direct compensation which was followed in the writer's experiment. The subject was placed in a Wheatstone Bridge, as in Smith's technique, but the current in the circuit was kept approximately constant throughout the experiment by means of a potentiometer.¹

Both moving coil (mirror) and string galvanometers have been used in psychogalvanic experiments. The majority of investigators have used the moving coil type, but Darrow (6), Richter (34), Syz (39), and others have employed the string galvanometer. This has also been used by Godefroy with whose apparatus a sensitive galvanometer relatively free from inertia is necessary. As Landis and DeWick (24, p. 67) observe it seems to make little difference which type of galvanometer is used.²

¹ The writer found in a preliminary experiment (unpublished) that Wechsler's method of keeping the current constant by use of the potentiometer, and Smith's method of statistical compensation for changes in apparent resistance (by calculating percentages of the mean), gave very similar results.

² Davis (27) following the argument of Dunlap (28) has argued that the string galvanometer is superior.

Types of Electrodes. A great variety of types of electrodes—brass, zinc, copper, tin, bronze and nickel—has been employed. Ostwald's normal calomel electrodes were used by Starch (37), Jeffress (21), Wells and Forbes (47), and others.

Among recent investigators, A. D. Waller (43), Stevanovic (38), and Smith (36) used metal plates covered with chamois skin soaked in normal saline solution. Metal electrodes attached to the body by kaolin paste were used by Richter (35) and by Syz (39). Lauer (25) used an inverted glass funnel filled with various solutions.¹ Clay cups of normal saline solution set in glass containers of saturated solution of zinc sulphate, with bars of amalgamated zinc inserted in the sulphate, were employed by Wechsler and have been used in the present study.

Choice of Apparatus. It will be seen that the choice of apparatus for psychogalvanic experiments is a very difficult matter. All methods have annoying disadvantages. For the present experiment the Wechsler apparatus seemed to provide more desirable factors than any other which was available to the writer when the experiment was begun. It takes care in a fairly adequate and convenient way of the problem of maintaining a constant current.² It permits of a convenient photographic record, thus insuring accuracy and permanence. Moreover, it may easily be handled by a single experimenter, without an assistant. Several of the other types of apparatus have points of superiority over Wechsler's, but most of them also have serious liabilities.³ It seems that Wechsler's method is still one of the more satisfactory means of measuring the response.

3. PSYCHOGALVANIC INVESTIGATIONS OF MENTAL WORK

Space does not permit an adequate general discussion of the extensive and controversial literature concerning the psychogalvanic response. The reader is referred to the excellent summaries and reviews of Grün-

¹ This summary concerning electrodes is based on Landis and DeWick's discussion (24, pp. 67-68).

² Davis (73) claims that Wechsler's method of keeping the current constant is satisfactory only so long as the ratio of the Bridge resistance to the total resistance in the circuit is unchanged; otherwise it causes a disturbance of proportionality. It is hardly profitable here to argue this point; in any case the major results of the present experimentation could not be greatly affected by such an error, since the deflections which are being compared are in general those given by a single subject during one brief sitting, or else an average of such results.

³ With the Godefroy apparatus, at best, it is necessary to use great care in making and breaking the circuit in order to avoid shocks from the transformer. The Hathaway instrument, at the time when this experiment was begun, seemed still too much in an experimental stage to make its use desirable. The report of the Davis apparatus did not appear until after this experiment was completed. Davis recommends the Hathaway instrument (with some reservations) but considers Godefroy's technique of little value; in Davis' opinion it gives a distorted record of the electrical change in the subject. Davis' apparatus has the disadvantage of being very complicated and expensive.

baum (17), Prideaux (30), Woodrow (51), Landis and De Wick (24). Of these the most recent and comprehensive is that of Landis and De Wick, published in 1929. A supplement by Landis carries this up to 1932. (See *Addendum*.)

However, as an orientation for the experimental study to follow an account of the previous applications of the psychogalvanic technique to the study of mental work will be worth while.

Many observations, but few careful experiments, have been made in regard to the relation of psychogalvanic responses to mental work.

In 1918 M. D. Waller (45) found that subjects who rated above the mean on a physics examination showed on the average larger psychogalvanic changes to various stimuli (not the physics test questions themselves) than students who rated below the mean.¹

A probably valid criticism of Waller's results was made by Jefferson (20), who computed the actual correlation between the physics scores and the deflections, finding it to be only $+ .17 \pm .024$, and considered Waller's methodology statistically unsound in other respects.

Most other experimenters have been less ambitious than Waller and have contented themselves with observing changes which take place during the actual course of mental work.

Tarchanoff (40) found that multiplication requiring effort produced the response. Veraguth (41), with one subject, found that silent reading of a dry scientific report produced little galvanic change, compared to reading for the same length of time a report of a patriotic speech—evidence to Veraguth's mind that the reflex is an indicator of "feeling tone" (*Gefühlsbetonung*) rather than of mental effort.²

Starch's Experiment with Physical and Mental Work. One of the most detailed experiments with mental work and the p.g.r. was carried out by Daniel Starch (37) with 10 subjects and the simple Veraguth circuit without the Wheatstone Bridge and without attempting to control the current.

He did not attempt to analyze deflections following individual stimuli, but recorded the general curves that occurred during periods of physical and mental work. The chief results may be summarized as follows:

1. A typical passive curve (when subject is doing nothing) runs along by small zigzags on the same general level.

¹ Porter (29) reports a preliminary investigation in which he found with 40 men and women college students that those of higher mental level, as judged by a psychological examination, tended to show greater psychogalvanic reactivity. Women showed greater reactivity than men.

² Other investigators who have made incidental observations on the p.g.r. in relation to mental work are Binswanger (4) who found no deflections while the subject was reading a university lecture, Peterson and Scripture (27) and Moravcsik (26) who found that electrical changes accompany various kinds of mental work, but are larger in "emotional" situations, and Gregor (16) who obtained larger deflections for difficult than easy arithmetical problems (type not specified).

2. During mental work (fixating a cross and trying to observe all of a row of six capital letters 12 centimeters to the right of this) there was with the exception of one subject, a rise in the curve (fall in resistance). The rise was usually most sharp at the beginning of the mental work. The work period was, of course, very brief as the subject was instructed to stop when he felt discomfort.

3. During a period of automatic mental activity (recitation to self of multiplication tables) there was a very slight rise in the curve (decrease in resistance.)

4. The rise in the curves was generally less for the mental work than for muscular work (rhythmic lifting of the right knee.)

Starch concluded that "those types of mental processes which are accompanied by the most distinct and widespread physiological changes produce the largest deflections, such as muscular activity in lifting knee, strong emotions accompanied by start or shock, halting and quickening of respiration, muscular tension, etc." (p. 36).

Affective Tone and P.G. Deflections During Mental Work. The determination of the part played by affective tone in producing p.g. deflections during mental work was attempted by Radecki (32) at the University of Geneva. Working with two or three subjects, he made some experiments in mental multiplication of two-place numbers. The subject was given, for example, the number 23 and told that he was to multiply it by a number which would be given to him in a moment. After a lapse of thirty seconds he was given the number 14 and told to multiply.

With the galvanometers ordinarily used the latent period for the p.g.r. is usually two or three seconds, never more than five or six. When the time between the giving of the number 14 (beginning of mental work) and the p.g.r. was counted, it was found that this period never corresponded in length with the ordinary latent time for the p.g.r. In most cases it was longer. In Radecki's opinion, this can be explained only by assuming that the p.g.r. is absolutely independent of the intellectual work itself and that it depends wholly on a process of emotional excitement, resulting from meeting a difficulty in the problem. However, as far as the present writer can see, there is no proof in such an experiment that the subject began "mental work" immediately after the appearance of the stimulus. Mental inertia might easily delay the beginning of actual work for several seconds.

Continuing Radecki's work at Geneva, Abramowski (Kühne, 22) experimented with twenty subjects of both sexes (university students), also using multiplication of two-place numbers as the stimulus situation. The multiplicand was given at the beginning of the experiment and the multiplier twenty seconds later. Amplitude of deflection varied for different subjects. The deflections usually occurred at the beginning of the

calculation. Certain subjects, generally those who were good in arithmetic, gave no deflections whatever. "Si la personne qu'on observe présente le type de l'attention qui se concentre sans agitation et une facilité pour le calcul mental, en sorte que son effort d'esprit est dépourvu de toute émotion, dans ce cas le calcul, même assez difficile, ne donne aucune réaction galvanométrique, quoique l'effort mental existe, et puisse même être assez intense." (p. 170)

As a result of incidental observation of arithmetical calculations (multiplication) Phillipson and Menzerath (28) concluded that it is not so much the relative difficulty of the calculation as the emotion that accompanies it which matters. For example, a good mathematician gave no notable deflection until he found that he had made a mistake.

Incidence of P.G. Reactions During Continuous Mental Work. Wechsler (46, p. 114) mentions a series of experiments in which he tried to separate the effects of mental effort from the effects of emotion, so far as these are related to the galvanic response. He tested his subjects with mental arithmetic examples of the following type: 7, plus 3, plus 6, divided by 2, minus 3, plus 8, minus 5, times 4, minus 8, divided by 4 equals? He notes that this type of problem is of much longer duration than those previously employed.

It was found by Wechsler that with such examples the deflection was always largest at the beginning of the problem. In many cases the main deflection occurred even before the problem was begun, when the subject had merely been given a signal. Only in a few cases did any deflections occur during the solution—these when the subject met with some difficulty.

In Wechsler's opinion these observations add further evidence "that it is the accompanying affective tone of mental effort . . . that provokes the galvanic reaction."

Relation of Acts of Choice and Judgment to the P.G.R. Two rather careful experiments have been performed on the relation of acts of choice and judgment to the p.g.r.

As part of a comprehensive study on "The Phenomenology of Acts of Choice" Wells (49) gave an account of a psychogalvanic study of five subjects (members of the London University department of psychology) who were asked to make choices between liquid tastes of varying hedonic quality, some pleasant, some unpleasant and some neutral; all odorless, colorless and labelled only with nonsense syllables. (This apparently is in part the same experiment as a previous one (48) reported by Wells in 1924).

She found that in all five cases the average percentage drop in resistance was greater in the case of difficult choices than for the average of all choices. Moreover, the average percentage fall for all choices was

in every case higher than the average percentage fall for "habitual" choices. Wells states (p. 28), "What appeared most constantly on introspection was what may be termed the conscious conative effort to perceive this [the stimulus]—the direction of 'attention' toward it (as distinct from physical effort.)"

A somewhat similar experiment is reported by Stevanovic (38). Five subjects (all trained psychologists) were used. They were required to learn a series of irregular figures of the "ink spot" type, classified, according to certain similarities in shape, under nonsense names such as "mevoz" and "bogil." Cards with completion sentences, such as "all bogil are _____, Second sabom is _____." were presented to the subject, who was required to complete the sentence with an appropriate descriptive term. After each reaction the subjects' introspections were dictated. Stevanovic found only a very rough correlation between difficulty of solution as indicated by the introspective reports, and occurrence or amplitude of psychogalvanic deflections. In many cases deflections of some size occurred where the subject reported no particular difficulty. Stevanovic explains this by saying, "Although any one special case of this kind [completion sentence] may not be very difficult for him [the subject], when he comes to make his judgment the mere apprehension that the stimulus has to do with a judgment of this kind arouses his 'alertness'" (p. 133). Both Wells and Stevanovic, then, consider that conation rather than emotion or affective tone is the essential conscious correlate of the p.g.r.

Influence of Effort on the P.G.R. Psychogalvanic changes occurring during mirror drawing were recorded by Gopalaswami (15). He found that increasing practice was accompanied by "increasing deflection of the galvanometer needle." Since the increased facilitation, as learning goes on, should lead to decrease of emotional excitement, the author concluded that the p.g.r. readings may be an indicator of "increased learning effort."

An ingenious approach to the general problem of what the p.g.r. means psychologically was made by R. B. Cattell (5) in an elaborate experiment with ten subjects who had repeated sittings. Mental work was one of the topics investigated. Cattell used a wide variety of stimuli which he classified under three main headings, as evoking conation, feeling, or cognition. He fails to tell the actual stimuli used, but does classify them under sub-headings as:

Conation—Attention (act of attending); tension (bodily and mental); effort, opposition (conative side of the instinct of pugnacity); action on a mental set; etc.

Feeling—Fear; disgust (loathing, etc.); curiosity; anger; etc.

Cognition—Critical examination (of stimuli with comparisons, etc.); memories; anticipation; etc.

As a result of comparing size of deflection following these different types of stimuli, Cattell concluded that "the reflex is more nearly proportional to the conative elements in any experience than to the affective or cognitive elements." The absence of specific information as to the stimuli employed makes it difficult to judge of the value of this experiment.

A minor experiment on problem solving is reported by R. J. Bartlett (3) who, working with only two subjects, had each one solve mentally three equations of increasing difficulty, and multiply mentally three two-place numbers of increasing difficulty. There was a tendency toward increase in deflection with the increase in difficulty. The author is cautious about ascribing this wholly to conative changes, however, and concludes as a result of comparative experiments with other types of stimuli that deflections occur both when conative and when affective changes are felt by the subject.

In an experiment of T. M. Abel (1), 20 problems of the following type were given to each of 6 subjects:

(a) Analogies, e.g., $\frac{\text{Volcano}}{\text{Igneous}} :: \frac{\text{Earthquake}}{\text{Granite}}$

(b) Statements of fact, e.g., "Oxygen is heavier than ozone."

Abel found that "the subject's attempt to solve or at least to comprehend the problem presented was frequently, but not always, accompanied by a deflection of the galvanometer." She believes that the electrical changes accompany certain reportable attitudes ("Bewusstseinslagen") which represent "sudden, decided and momentary checks" in the solution of the problem. These she thinks can hardly be classed definitely as either emotional or conative.

"Tension" as an Explanation of P.G. Deflections. Both mental and physical work were investigated by M. M. White (50) who took records of electrical changes occurring during work with the dynamometer, and during work with multiplication problems. These were compared with the changes in electrical resistance during relaxation and sleep. It was concluded that electrical resistance is higher in relaxation than in tension, a fact of which White believes previous investigators have taken too little notice.

Conclusions. No clear cut point of agreement seems to have resulted from these investigations of mental work, though they tend to indicate that the larger deflections may take place when difficulties, tensions, and checking situations occur. Interpretation of results is extremely variable.

4. THE PSYCHOLOGICAL SIGNIFICANCE OF THE GALVANIC RESPONSE.

A vast amount of discussion has centered around the question of the psychological significance of the p.g.r. Though no general consensus of

opinion has resulted, the present writer believes certain convergent trends which may help to clarify the question appear not only in the investigations relating to mental work, but throughout the literature—both physiological and psychological—relating to the response.

Early writers and many later ones usually associated the p.g.r. with emotion, without much attempt to analyze that term. Later writers have tended either to analyze emotion and to correlate the response with some factor subsumed under emotion, or to correlate the response with some function or group of functions—conation, attention, orectic process, tension, etc.—which overlaps or includes emotion as ordinarily understood, but where emotion is not considered the essential concomitant of the p.g.r.

One sees emerging from the experimentation an increasingly refined and critical analysis of the psychological meaning of the p.g.r., and one perceives a certain core of agreement centering around something underlying and intimately connected with both emotion and conation but not satisfactorily delimited by either term.

The P.G.R. as an Indicator of Energy-Expenditure. What is this underlying something? May one not reasonably consider it to be a hyper-functioning of the sympathetic (thoracico-lumbar) division of the autonomic nervous system and the organs which are innervated by this division?

There are several lines of evidence which justify the suggestion that the p.g.r. may be considered at least a rough indicator of sympathetic activity. (1) There is the direct evidence of several well-controlled physiological and neurological experiments—in particular an experiment of Foà and Peserico (12)—which seem to show quite conclusively that the skin organs responsible for the p.g.r. are innervated by some portion or portions of the autonomic nervous system. (2) Experimenters are quite generally agreed that increased p.g. responses characteristically occur in emergency situations of some sort.¹ The connection of hyper-activity of the thoracico-lumbar division of the autonomic with emergency situations seems well established by the work of Cannon and others. (3) Introspective reports from psychogalvanic experiments generally agree in describing conscious experiences which occur characteristically in meeting emergency situations.

¹ See footnote on page 55, this paper.

CHAPTER II

THE EXPERIMENTAL PROCEDURE

Briefly outlined, the main substance of the writer's investigation is as follows: Subjects were required to find orally the sums of addition examples,¹ while the amplitude of the galvanic deflections occurring during this mental work was recorded. Examples of varying complexity² were presented in different sequences with no time limit. Examples of approximately equal complexity were presented in various sequences with a limited time allowance.

1. THE ARRANGEMENT AND USE OF APPARATUS

The Psychogalvanograph. The basic apparatus used in these experiments was the Wechsler psychogalvanograph (manufactured by C. H. Stoelting Company). The instrument consists of a d'Arsonval galvanometer, Wheatstone bridge, and a dark chamber containing a mechanism for taking photographic records by means of impressions from a line of light reflected from the galvanometer mirror. The excursions of the line of light may be read from a translucent millimeter scale while they are being photographed. The apparatus includes connections for attaching a timing device and a stimulus key by means of which small electric bulbs within the apparatus may be turned on and off leaving dots on the photographic record to indicate time intervals and moments when stimuli were applied.

Considerable alterations in the apparatus were made in order to meet the needs of the experimental situation. These can best be described in connection with the general set-up of the experiment.

General Experimental Set-Up. The examinations were given in a small inner room (about 10 x 10 ft.) where on most occasions little or no outside noise could be heard. The floor of this room was of concrete; the walls were of tile and plaster.

Figure 1 gives a general picture of the arrangement of apparatus. The galvanograph was placed on table H, (see Fig. 1) a heavy, firm laboratory table, 4 x 2½, and 2½ feet high. The millimeter scale on the apparatus was about four inches from the edge of the table facing the ex-

¹ Addition examples were selected as stimulus material because they seemed to offer the best opportunity for flexible, objective, and quite exact control of complexity or difficulty.

² There is objective evidence that in these experiments complexity is within certain limits equivalent to difficulty as shown by percentage of correct responses.

perimeter. There was nothing else on the table, and the galvanograph was remodelled in such a way that it was unnecessary to touch it or the table during the experiment. The table was not in contact with the walls and was arranged in such a way that no other article of furniture touched it. Felt pads one inch in thickness were placed under the legs to reduce the chances of vibration.

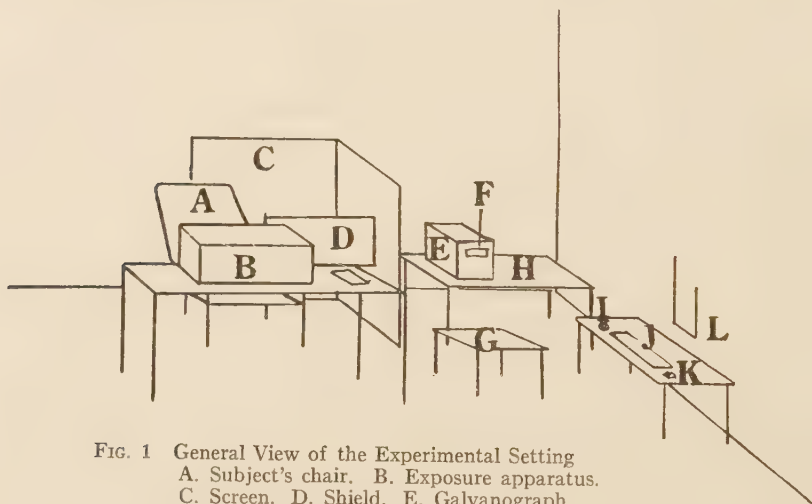


FIG. 1 General View of the Experimental Setting
 A. Subject's chair. B. Exposure apparatus.
 C. Screen. D. Shield. E. Galvanograph.
 F. Millimeter scale. G. Examiner's stool.
 H. Galvanograph table. I. Potentiometer.
 J. Wheatstone Bridge. K. Voltmeter. L. Seconds Pendulum.

The subject was seated about 18 inches to the left of this table, facing in the same direction as the psychogalvanograph and separated from the table (H) by a screen so that she was unable to see the apparatus during the examination.

The experimenter was seated directly opposite the psychogalvanograph, about one foot from the table, a position from which he could conveniently read the millimeter scale.

Directly in front of the subject and at a horizontal distance of about two feet from her eyes, an exposure apparatus was placed on a narrow stand, about one foot wide, so built that the exposed material appeared about on a level with the eyes.

The end of this stand was directly to the left of the experimenter's chair where he could easily operate the exposure apparatus with his left hand. Room was left on the stand for a sheet of paper where records of the galvanometer readings and other information could be noted. A heavy cardboard screen was so arranged that the movements of the experimenter could not be seen by the subject.

In order to eliminate the vibration of the galvanometer caused by handling the psychogalvanograph in its original form, the Wheatstone bridge was removed from the rest of the apparatus—a specially constructed cover being made to take its place as a “ceiling” for the dark chamber. The bridge was placed on a bench about two feet high directly to the right of the experimenter where he could easily manipulate it without moving from his chair. The new connections were carefully soldered. The switch for operating the motor which unrolled the film was also removed from the galvanograph and placed on this bench where it could be reached conveniently by the experimenter.

A potentiometer was placed in circuit with the bridge ¹.

The current was supplied from two Burgess C radio batteries, connected in series so that the total available E.M.F. was 12 volts. This could be reduced to as little as one-quarter volt by use of the potentiometer. In this study it proved unnecessary ever to use more than 9 volts or less than about one-third volt. A 15-volt Weston voltmeter, reading to quarters of a volt, was kept in the circuit.

The Exposure Apparatus. A few words of description should be given to the exposure apparatus, which was one designed by Professor J. F. Shepard of the University of Michigan for use in memory experiments.

The various series of arithmetic examples constituting the material to be exposed were typewritten on 30 inch strips of adding-machine paper $2\frac{1}{2}$ inches wide. The ends of the typed strips were glued together so as to form rolls. These rolls were placed on the apparatus over two drums which were moved by means of a lever and weight arrangement so that the examples could be made to appear one after another through a slit in a metal sheet which concealed the drums from the subject. A stimulus could be held in sight of the subject through the aperture for as long a time as desired, or, by moving the lever rapidly, it could be made to appear and disappear within one second or less. The aperture was very clearly illuminated by means of a goose neck lamp so placed, on a table behind the subject's right shoulder, as to throw its light against the opening without too much glare.

As has already been explained, the psychogalvanograph contains an arrangement for switching on a small electric signal bulb, placed within the apparatus, so that the moment of the application of the stimulus may be indicated on the edge of the film by a dot of light. This is usually done by depressing a telegraph key.

The exposure apparatus, however, is so constructed that the telegraph key was unnecessary in this experiment. Small metal rods are placed so as to protrude from the circumference at the edge of one of the drums.

¹ See p. 16 for a more complete description of the circuit.

As the drum revolves, these rods successively make and break contact with a stationary metal brush. The brush was put in circuit with the signal bulb on the psychogalvanograph, so that the bulb was switched on at the moment when an example appeared in the aperture and turned off when the example disappeared, thus giving automatically a film record of the appearance of each stimulus example.

It was originally intended to keep also a photographic record of time intervals by means of a seconds pendulum placed in circuit with the other signal bulb of the psychogalvanograph. After many unsuccessful trials this attempt was abandoned, since, owing to some defect in the apparatus or set-up, very few of these film time records were satisfactory. For the main purposes of this experiment an exact time record is in any case of slight importance.

The Electrodes. The electrodes used were of the type devised by Wechsler. They consist of two clay cups containing normal salt solution, placed in larger glass cups of saturated solution of zinc sulphate. Two zinc rods are immersed in the zinc sulphate, and these are connected by wires with the galvanometer and Wheatstone bridge. This type of electrode is comparatively non-polarizable.

Both the clay cups and the glass cups were graduated so that the salt solution and the zinc sulphate solution were kept at a constant level. This level was checked for each subject. The salt solution was changed daily. The room temperature was kept approximately constant—about 68 degrees, though the temperature of the solution was not otherwise controlled.

The subject was seated comfortably in a Morris chair, the back of which was inclined just enough to give a normal relaxed sitting position. The electrodes were attached to the end of the left arm (subject's left) of the chair.

During the experiment the tips of the index and second fingers of the subject's left hand were placed one in each of the cups of salt solution. The tip of each finger was immersed in the solution as far as the first joint. To keep conditions as nearly constant as possible, each of these fingers, between the first and second joints, was insulated by a coating of heavy vaseline. Over the vaseline, to prevent any chance of its rubbing off and to preserve a straight edge at the joint, a strip of one-half inch hospital adhesive tape was wrapped firmly, but not tightly enough to cause constriction.

In order to make it possible to insert the fingers for the proper distance into the salt solution in such a way that the subject could maintain this position without strain or discomfort, a movable wooden platform about 4 x 4 x $\frac{1}{2}$ inches was constructed on which she rested the palm of her hand. The edge of this platform was placed so that it protruded for

about one-fourth inch over the edge of the clay cups. On the platform the palm of the hand rested so that the joints between the palm and the fingers came at its edge.¹ The platform was then raised or lowered to such a height that the level of the salt solution in the cups came about half way up the insulating bands which encircled the fingers. It was tilted at such an angle that the subject's hand and fingers came to rest comfortably. Before being placed in the solution the subject's fingers were washed with grain alcohol. The fingers not immersed were allowed to come to a comfortable position, usually hanging slightly over the edge of the platform a little to the left of the cups. A band of electric insulating tape covered the top edge of the cups so that the edges could not be accidentally touched by one of the "outside" fingers.

The left forearm rested on a pad of felt about 1 inch thick, 6 inches wide, and 18 inches long placed on the arm of the chair immediately behind the platform; the wrist was supported on a small felt pillow placed on top of the felt pad, so that the entire arm was supported in a comfortable fashion.

Experimental Technique. In the writer's experiment, essentially the same technique was used as that described in Wechsler's *Measurement of Emotion* (46, pp. 59-60). Quoting from Wechsler:

To perform an experiment, one employs the following procedure.² The electrodes EE' are attached to the subject. This done, the double switch is turned on to the poles marked 11'. This throws the subject into simple series with the source of current and the galvanometer. The galvanometer is then shunted to the lowest sensibility and the circuit is closed.

When the circuit is closed there will be an initial excursion of the galvanometer indicating the passage of an intensity of current that will depend upon the particular body resistance of the individual, but this intensity may now be varied as desired by means of a potentiometer. The potentiometer is manipulated until the galvanometric deflection attains a magnitude which corresponds to a particular intensity which one has chosen to work with. At this point the switch is turned on to poles PP' which throws the subject into the Wheatstone Bridge. The galvanometer is next shunted back to its higher sensibility and the Bridge is balanced by means of the rheostat (B.R.). The balancing of the Bridge informs us of the subject's resistance and at the same time brings the initial deflection back to the zero starting point. One is now ready to begin the experi-

¹ The movable platform rested on the ends of four specially threaded bolts about six inches long, which fitted into holes bored about half way through it on the under side. Each of these bolts was screwed through two nuts, one on the lower and one on the upper side of the stationary platform to which the electrodes were attached. The platform could be raised or lowered to any desired height or angle by turning the bolts separately.

² See Figure 2.

ment. If as a result of an emotional response the body conductivity becomes significantly reduced so as to make a noteworthy change in the intensity of the current flowing through the circuit, one breaks the circuit momentarily, turns the switch back to poles 11' and again by means of the potentiometer regulates the amount of current passing through the circuit to correspond to the initial intensity. When this has been done the switch is turned back to poles PP', which again throws the subject into the Wheatstone Bridge and the experiment may be continued. In this way the intensity of the current can be kept constant throughout a prolonged experiment irrespective of the continued variations in body resistance which may occur.

Although the writer did not use a milliammeter, the intensity was kept approximately constant by noting on the translucent scale the deflection that occurred when a fixed resistance of 10,000 ohms was put in the circuit

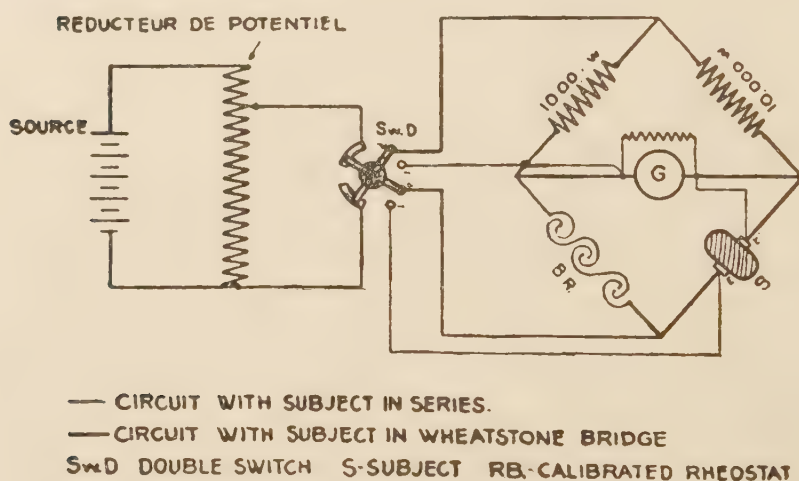


FIG. 2 Modified electric circuit for measurement of galvanic response, enabling experimenter to regulate intensity of current flowing through circuit. (From Wechsler; 46, p. 59)

in place of the subject, against an E.M.F. of 1 volt. The point on the scale (to the nearest millimeter division) which the deflection reached under these conditions was used as the indicator of the fixed intensity kept throughout the experiment. That is, no matter what the initial deflection of a subject, the line of light was brought back to this point on the scale before balancing the bridge. Consequently, in the case of every subject, regardless of his initial resistance, the experimenter was working always with a fixed intensity of approximately the ratio 1 volt to 10,000 ohms.

Changes in the subject's resistance during the experiment were compensated for within fixed limits by readjusting the potentiometer whenever the line of light after a deflection did not return to a point on the scale within 10 millimeters to the left or 5 millimeters to the right of the zero point within about 30 seconds. It would have caused an impracticable number of readjustments to make the scale limits any narrower.

In addition to being recorded photographically during the experiment, the subject's deflections were read from the translucent scale. The scale reading and the photographic record for each deflection were checked in recording the results, and found to correspond within close limits. In case of disagreement, the photographic record was of course preferred.¹ A record was also kept of the initial resistance of each subject.

2. THE SUBJECTS

The 24 subjects with whose records these experiments deal were all undergraduate girls in the junior and senior years of the School of Education of the University of Michigan. Thus the factor of age was held constant within quite narrow limits. One subject only was above the usual junior and senior age range. It was considered desirable to hold the factor of sex constant in an experiment where emotional disturbances may be of paramount importance.²

Surprisingly enough there are very few psychological experiments with the p.g.r. where any attention has been paid to either the age or the sex factor; and none, the writer thinks, with a number of subjects approaching that of the present experiment, where both age and sex have been held even approximately constant.

Directions Given to Subjects. The purpose of the experiment was explained to every subject before a practice sitting. At that time she was allowed to see the apparatus, though it was hidden during all the actual experiments. It was felt that this method was the best way of inducing a calm and natural attitude. The subject was directed to sit quietly in the chair and to avoid making sudden or gross muscular movements. She was, of course, directed to be particularly careful to avoid moving the hand in the electrodes. She was told not to continue in a strained position if she felt uncomfortable, but to tell the experimenter so that he could suspend the experiment for a moment in order to give her a chance to move.

If the subject inadvertently moved the hand in the electrode or made some sudden or gross muscular movement, she was asked to report it at once to the experimenter. Deflections due to sudden movements are in

¹ No doubt scale readings alone would prove sufficiently accurate for many purposes, but for detailed studies involving small numbers of cases the added accuracy and certainty of the photographic record is an important advantage.

² See the article of Rein (33) for evidence that there may be physiological sex differences in the p.g.r.

any case usually very easily detected by the absence of a latent period. All deflections where muscular movement was reported by the subject or where there was no latent period were omitted in working with the results.

At every sitting the subject was told the general nature of the test she was to be given that day. (See description of tests). In order to accustom the subjects to the situation before beginning the experiment proper, each one was given a preliminary test using a series of easy examples of similar difficulty taken from Courtis' Standard Practice Tests in Addition.¹

Distribution of Subjects. Six different tests were finally adopted as material for the experiments. Of the 24 girls whose records were used, 21 satisfactorily completed three tests besides the practice test and 8 satisfactorily completed four tests in addition to the practice test. Hence no one subject took all of the six tests, and most subjects took only three of them. Although not as systematic as it might have been, the rotation of the tests was probably accurate enough for the purposes of this experiment.² Details of the rotation are given in Table I.

TABLE I
THE NUMBER OF SUBJECTS TAKING THE DIFFERENT TESTS

Tests	Test Taken First	Test Taken Second	Test Taken Third	Test Taken Fourth	Test Taken Fifth
Complexity 1 Easy-Difficult	5	3	1	0	
Complexity 2 Difficult-Easy	4	4	3	1	
Complexity 3 Alternating	4	5	4	3	
Speed 1 6-15 Fast	3	7	0	1	
Speed 2 11-20 Fast	3	4	2	1	
Speed 3 Alternating	2	0	8	2	1

It was necessary even with the tests which were finally adopted to discard a number of records. In some cases the subject was unusually nerv-

¹ See page 21.

² It was originally planned to give six tests besides the preliminary test, to each of 20 subjects, but after proceeding some way with the experiment it became evident that two of the original six tests were unlikely to show significant results. Consequently, these tests were discontinued and others substituted, with the result that within the limited time in which it was necessary to complete the work it was impossible to carry out the experiment in quite the systematic fashion desired.

ous or restless and showed so much muscular movement and twitching as to invalidate the record. In other cases some part of the apparatus failed to work properly during the experiment. On a few very cold days in winter it was impossible to obtain satisfactory records from some subjects.

3. THE STIMULUS MATERIAL

The tests used as stimulus material each consisted of 20 examples in addition. In three of the tests, called the Complexity Tests, the complexity (difficulty) of the test material was varied, while the time factor was held constant in the sense that the subject was given all the time she needed to do each example. In the other three tests, called the Speed Tests, the complexity (difficulty) of the tests was held constant,¹ while the rate of performance (time allowed for each example) was varied.

Each subject was given a practice test consisting of 20 easy examples of approximately equal difficulty, before taking any of the regular tests. On the practice test there was no time limit.

A detailed description of the six regular tests is needed to make their purpose clear. All tests, it will be noted, begin with five examples of approximately equal complexity. Experiments with word series have shown conclusively that deflections corresponding to the first four or five items are in some way so much magnified due to the commencement of the new situation that changes due to other factors are obscured.

A word is needed in regard to the length of time elapsing between presentation of examples. After each galvanometer deflection an interval was allowed long enough to enable the line of light to return approximately to rest, plus an additional 30 seconds during which the light remained nearly in the same position. Then the next example was presented. If no deflection occurred, the new example was presented 30 seconds after its predecessor. Subjects were warned that there would be a varying interval of time between different examples and were told that the experimenter would always give the preparatory signal, "All right," just before presenting an example. They became accustomed to this procedure on the preparatory tests before taking any of the regular ones.

The Complexity Tests. A series of 20 addition examples of varying complexity was devised by the writer. The same examples (with slight alterations as explained below) were arranged in three different tests.²

The first ten examples of Test 1 were kept at approximately the same degree of complexity in order that the commencement effect might have worn off before any experimental change was introduced. It was thought

¹ See page 21 ff.

² The subjects did not orally report the sums backward as they added, but gave the total sum from the left after they felt they "had the answer." They were allowed to make oral corrections, however.

that otherwise the effects of the apparently slight experimental change in the tenth example might be obscured. After this example the test was increased in complexity by regular and gradual steps.

The initial six examples of Test 2 were kept at an approximately constant degree of "high" complexity in order that the first examples of decreasing complexity should not be influenced by any element of "startle."

COMPLEXITY TEST 1. EASY-DIFFICULT

1.	1 2	6.	6 3	11.	8 13	16.	4528 6879
2.	3 3	7.	4 2	12.	63 98	17.	9759 42234
3.	3 5	8.	5 4	13.	57 324	18.	52639 66967
4.	2 3	9.	7 3	14.	518 987	19.	57885 124134
5.	6 7	10.	2 5	15.	885 3131	20.	384916 965879

COMPLEXITY TEST 2. DIFFICULT-EASY

1.	825486 592875	6.	384916 965879	11.	885 3131	16.	2 5
2.	988745 345627	7.	57885 124134	12.	518 987	17.	7 3
3.	527847 634989	8.	52639 66967	13.	57 324	18.	5 4
4.	476385 787438	9.	9759 42234	14.	63 98	19.	4 2
5.	275764 853437	10.	4528 6879	15.	8 13	20.	6 3

COMPLEXITY TEST 3. EASY-DIFFICULT ALTERNATED

1.	1	6.	384916	11.	5	16.	885
	2		965879		4		3131
	—		—		—		—
2.	3	7.	57885	12.	4	17.	518
	3		124134		2		987
	—		—		—		—
3.	3	8.	52639	13.	6	18.	57
	5		66967		3		324
	—		—		—		—
4.	2	9.	2	14.	9759	19.	63
	3		5		42234		98
	—		—		—		—
5.	6	10.	7	15.	4528	20.	8
	7		3		6879		13
	—		—		—		—

The purpose was to obtain a curve of deflections accompanying a continuous relaxation of mental effort.

Save that the first five or "practice" examples were different, the examples in this test were the same as those in Test 1, but were arranged in reverse order.

The examples in Test 3 were the same as those in Test 1, except for a difference in arrangement. There was in this test a sudden increase from very simple to very complex examples, followed by a sudden decrease from very complex back to very simple ones. These simple examples were in turn followed by a second abrupt increase in complexity, after which there was a gradual decrease for the remainder of the test.

The Speed Tests. Three equivalent tests were prepared, each consisting of 20 simple addition examples of similar difficulty taken from the Courtis Standard Practice Tests in Arithmetic.^{1, 2}

While the complexity, or difficulty, of the examples in these tests was held constant, the rate at which the subject had to work was changed in various ways. In all three tests, some of the examples were given at a "slow" rate; that is, the subject had all the time she wanted in which to respond, and the example was presented on the exposure apparatus until she gave her answer. Other examples were presented at a "fast" rate; that is, the example was held on the exposure apparatus for only one second and the subject was required to respond before the end of another

¹ Speed Test 2 is the same as Speed Test 1 except that the order is reversed.

² S. A. Courtis, *Teachers' Manual for Courtis Standard Practice Tests in Arithmetic*. World Book Company, Yonkers, pp. 64.

PRACTICE TEST ¹
No time limit on any examples

1.	5	6.	3	11.	4	16.	5
	1		4		2		0
	9		9		9		2
	—		—		—		—
2.	5	7.	8	12.	4	17.	2
	2		1		9		4
	6		5		6		6
	—		—		—		—
3.	1	8.	1	13.	3	18.	4
	7		8		6		7
	7		3		8		4
	—		—		—		—
4.	7	9.	5	14.	4	19.	8
	0		0		2		4
	1		6		3		7
	—		—		—		—
5.	7	10.	9	15.	6	20.	6
	2		6		7		3
	4		8		5		1
	—		—		—		—

SPEED TEST 1
Examples 1-5, slow; 6-15, fast; 16-20, slow

1.	5	6.	4	11.	3	16.	4
	4		3		4		5
	7		1		8		9
	—		—		—		—
2.	6	7.	4	12.	4	17.	2
	5		9		7		4
	8		3		4		8
	—		—		—		—
3.	9	8.	9	13.	8	18.	5
	2		7		9		1
	3		0		3		6
	—		—		—		—
4.	5	9.	5	14.	3	19.	5
	1		1		9		6
	5		8		9		9
	—		—		—		—
5.	1	10.	4	15.	7	20.	9
	3		9		2		6
	8		7		8		5
	—		—		—		—

Warning Signal

Warning Signal

¹ This was the first test given to every subject, no matter whether her next test was a complexity test or a speed test.

SPEED TEST 2

Examples 1-10, slow; 11-20, fast

1.	9	6.	7	11.	4	16.	1
	6		2		9		3
	5		8		7		8
	—		—		—		—
2.	5	7.	3	12.	5	17.	5
	6		9		1		1
	9		9		8		5
	—		—		—		—
3.	5	8.	8	13.	9	18.	9
	1		9		7		2
	6		3		0		3
	—		—		—		—
4.	2	9.	4	14.	4	19.	6
	4		7		9		5
	8		4		3		8
	—		—		—		—
5.	4	10.	3	15.	4	20.	5
	5		4		3		4
	9		8		1		7
	—		—		—		—

Warning Signal

SPEED TEST 3

Examples 1-5, slow; 6-10, fast; 11-15, slow; 16-20, fast

1.	5	6.	5	11.	6	16.	7
	9		2		7		6
	2		6		6		6
	—		—		—		—
2.	1	7.	3	12.	8	17.	9
	3		9		1		3
	9		8		3		2
	—		—		—		—
3.	8	8.	7	13.	6	18.	7
	7		5		2		0
	8		4		1		4
	—		—		—		—
4.	7	9.	8	14.	4	19.	4
	5		0		8		4
	2		8		5		8
	—		—		—		—
5.	6	10.	1	15.	3	20.	9
	5		8		8		7
	5		9		7		3
	—		—		—		—

Warning Signal Warning Signal Warning Signal

second. In other words, two seconds were allowed between the appearance of the example on the exposure apparatus and the subject's response.

In the majority of cases this amount of time was sufficient to enable the subject to perceive the example and respond correctly, though it did, of course, require an increase in alertness and a heightened effort of attention which was objectively shown by a greater number of mistakes on these examples, as well as almost unanimously indicated by the subjects' introspective reports.

The changes in rate in the various speed tests were arranged as follows: In Test 1, Examples 1-5 were presented at the slow rate, Examples 6-15 at the fast rate, and Examples 16-20 at the slow rate. In Test 2, Examples 1-10 were presented at the slow rate and Examples 11-20 at the fast rate. In Test 3, Examples 1-5 were presented at the slow rate, Examples 6-10 at the fast rate, Examples 11-15 at the slow rate, and Examples 16-20 at the fast rate.

In all the Speed Tests a warning signal consisting of the words "Fast examples next" or "Slow examples next" was given just before a change in rate was introduced. A record was kept of the deflections following these warning signals.

In the Complexity Tests no warning signals were given.

CHAPTER III

EFFECTS ON THE PSYCHOGALVANIC RESPONSE OF CHANGES IN COMPLEXITY AND TIME LIMIT (GROUP RESULTS)

As a first step in dealing with the results of these experiments, the mean deflection for the subjects was found for each of the 20 examples in each of the 7 stimulus tests. The standard deviation for each of these means was also calculated. For every example in Complexity Test 3 and Speed Test 3 (the two tests with the greatest number of cases) a mathematical measure of skewness, a_3 , or $\frac{1}{\sigma_x^3} \cdot \frac{\sum \bar{x}^3}{n}$ was computed.¹ The latter measure was not considered of sufficient importance in regard to the main points at issue in the experiment to make necessary its further use.

1. COMPARISON OF MEANS AND STANDARD DEVIATIONS OF DEFLECTION CURVES

Comparison of the means and sigmas yields some interesting information.² The size of the sigmas is at first sight startling (see p. 26) though it is not surprising in view of the nature of the data. A survey of the mean deflections of the individual subjects on the different tests shows that there are vast individual differences between different subjects in regard to the average size of their deflections for the same stimuli. The mean deflections of some subjects are more than 20 times as great as those of other subjects taking the same tests, though differences so extreme as this are rare.³ For the *individual* subjects the mean total deflection for all tests (excluding the practice test) is 9.64 mm., with an S.D. of 5.68. In regard to the factors responsible for amplitude of p.g. deflections, there are apparently great individual differences in physical or mental make-up or perhaps both.

On the two tests (Complexity Test 3 and Speed Test 3) where a measure of skewness has been obtained for the *individual examples*, it is invariably positive and generally large. Seemingly, in the case of every ex-

¹ $\bar{x}$ denotes the variation of any observed value, $\bar{x}$, from the mean, Mx . For a discussion of a_3 see J. W. Glover and H. C. Carver, *Introduction to Mathematical Statistics*, p. 67 (Ann Arbor, Edwards Brothers, 1928).

² See footnote, p. 29.

³ Large individual differences in amplitude of deflection for the same stimulus have been noted or implied by many writers. See Wechsler (46), Farmer and Chambers (9), Lauer (25); but they have not been specifically measured and compared.

ample, the subjects giving very large deflections have a predominating influence. Obviously, the mean deflection-curves may not be fairly representative of the type of subjects who give very small deflections.

Similarity of Mean Amplitude of Reaction. Except for the Practice Test, and Speed Test 2 the total means (means of the 20 means) of each distribution are quite similar, ranging between 7.77 and 9.80.¹ As would be expected, the total mean for the Practice Test (5.96) is considerably lower than that for any of the other tests, since the Practice Test contains no critical examples.

Chance factors probably account for the large mean (14.65 mm.) of Speed Test 2. No other test group contains more than one subject whose mean deflection is above 20.00 mm. and none are as high as 30 mm. There are three such subjects (above 20 mm.) in the Speed Test 2 group, one of whom shows an average deflection of over 30.00 mm. With the two highest individual averages omitted, the total mean for Speed Test 2 becomes 11.00 mm.; with the three highest omitted, it is 9.58 mm. Aside from a chance distribution there is apparently no reason why the total mean for this test should be larger than that for the other tests.

It seems that, except for the Practice Test and Speed Test 2, the similarity of the total means warrants a rough comparison of amplitude of mean deflections corresponding to certain individual examples. This is particularly true for comparisons of deflections for the different complexity tests among themselves and the speed tests among themselves.

In addition to the total means it is advisable to consider the average sigma for each distribution, or better, the average coefficient of variation derived from the relation between the average sigma and the total mean.

Coefficients of Variability. A comparison of average C.V.'s for all seven of the tests shows a range of from 66.41 for Speed Test 1 to 98.57 for Complexity Test 2. That is, the average variability in amplitude of deflections accompanying the examples of Speed Test 1 is about 67 per cent of that for Complexity Test 2.

The average C.V.'s for the two types of tests among themselves show a narrower range. For the Complexity Tests they were respectively 74.34, 98.57, and 84.17. For the Speed Tests they were 66.41, 75.63, and 83.99. The average C.V. for the Practice Test was 85.40.

Hence it seems that, though the different tests are not as similar in regard to variability of deflection as they are in regard to central tend-

¹ Total means with average sigmas were as follows:

			Mean	S.D.				Mean	S.D.
Complexity	Test	1	9.47	7.04	Speed	Test	1	7.77	5.16
"	"	2	9.80	9.66	"	"	2	14.65	11.08
"	"	3	8.50	7.18	"	"	3	8.13	6.82

ency, the differences in variability are, nevertheless, in no case very great and between some tests are very slight. In all tests the variability is high.

A point to be emphasized, then, in regard to the statistical aspects of the data is that, while the subjects show a high degree of variability in the amplitude of their p.g. deflections to the same examples, these subjects are not much more variable on one test than they are on the others. Both in regard to the average amplitude of deflections and the variability, the results for the different tests are quite similar. In other words, there is a good degree of consistency in the results; a consistency which was to be hoped for in view of the similarity of the stimulus situations in the different tests.

Difficulty of Test Material. An interesting check on the influence of complexity and speed on the subject's actual difficulty in performance is provided by the number of subjects making errors in answering the various addition examples which serve as stimulus material. It goes without saying that an example's difficulty for the subjects would be imperfectly related to number of errors, since the factor of effort is not controlled; nevertheless, one would expect a fairly close relationship in averages. Table II shows that such a relationship is found in the present experiment. There is a close and consistent relationship between increase in complexity of examples and number of incorrect answers. Moreover, fast examples on the average result in more than twice as many errors as slow examples.

It will be noted that in both Speed Test 1 and Speed Test 2 the second set of five fast examples seems to be much easier than the first. This may in part be due to some sort of ocular accommodation. Possibly also an improved technique of attacking the problem is developed. However, there is no improvement in the second set of fast examples in Test 3, which is separated from the first set by a series of slow examples. On the whole, it seems not unlikely that the drop in errors in Speed Tests 1 and 2 is the result of a sort of general adaptation to the speed situation. As the situation continues, both the sense organs and the central nervous system in general become better adapted to it. It should be observed (Figs. 3-9) that a drop in amplitude of p.g. deflections accompanies the drop in number of errors made. Apparently there is also less sympathetic nervous disturbance as the subject becomes better able to cope with the situation.

Correspondence of Individual with Averaged Results. It may, perhaps, still be doubted whether, in view of the immense differences in size of average deflections of individuals, the curves for mean deflections present a true picture of the distribution. It might be that the form of these curves has been to a large extent determined by a few individuals who consistently give very large deflections. Evidence from records of

individual cases, which will be presented later, shows that *there are no very significant differences* in the general form of the curves of individuals who tend to give deflections of different degrees of amplitude—except perhaps for the two or three cases who give exceedingly small average de-

TABLE II
RELATION OF NUMBER OF ERRORS PER EXAMPLE TO COMPLEXITY OF
EXAMPLES AND SPEED OF PERFORMANCE

Complexity Tests			Speed Tests		
Test	Type of Example	Errors per Example	Test	Type of Example	Errors per Example
Test 1— 8 subjects			Test 1— 11 subjects		
Ex. 1-5	very simple	0.	Ex. 1-5	slow	1.0
Ex. 6-10	very simple	.2	Ex. 6-10	fast	3.4
Ex. 11-15	more complex	1.4	Ex. 11-15	fast	1.8
Ex. 16-20	still greater complexity	4.0	Ex. 16-20	slow	.6
Test 2— 12 subjects			Test 2— 10 subjects		
Ex. 1-5	most complex	5.8	Ex. 1-5	slow	.6
Ex. 6-10	less complex	4.8	Ex. 6-10	slow	1.4
Ex. 11-15	still less complex	2.0	Ex. 11-15	fast	2.4
Ex. 16-20	most simple	0.	Ex. 16-20	fast	1.6
Test 3— 16 subjects			Test 3— 13 subjects		
Ex. 1-5	very simple	0.	Ex. 1-5	slow	.8
Ex. 6, 7, 8	greatest complexity	7.0	Ex. 6-10	fast	2.4
Ex. 9-13	very simple	.2	Ex. 11-15	slow	.6
Ex. 14, 15, 16	medium complexity	4.3	Ex. 16-20	fast	3.0
Ex. 17-20	slight complexity	2.2			

flections.¹ In these cases the apparatus is hardly sensitive enough to show what the general form of the curve may be.

In view of this evidence and of the, in many respects, very consistent tendencies and striking similarities of the different mean deflection-curves, there is good reason to believe that these curves present a valid summary of the several aspects of the data.

Graphs of Averaged Results. The mean deflection curves which are

¹ Average deflections of less than 1.00 mm.

presented graphically in Figures 3 to 9 require a somewhat detailed discussion.¹

A word of explanation is needed for an understanding of the graphs. The numbers on the x-axis indicate the successive stimulus examples; the numbers on the y-axis, the average deflection in millimeters. It should

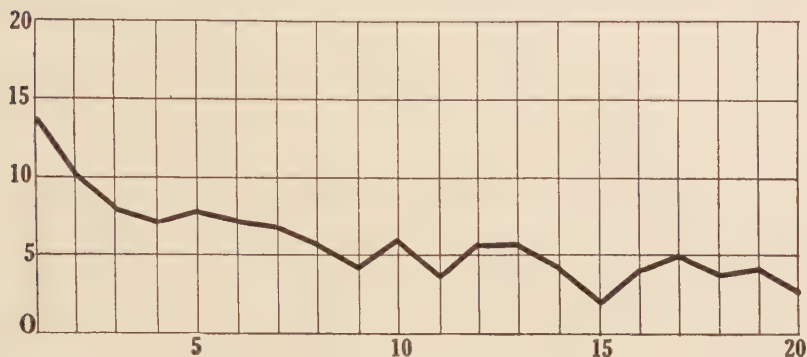


FIG. 3 Practice Test (14 cases) All Examples Easy.

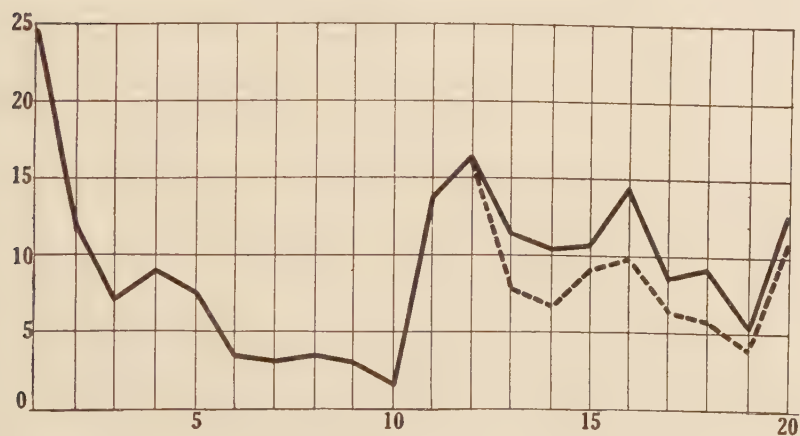


FIG. 4 Complexity Test 1 (8 cases) Easy—Difficult.

be noted that the dotted lines have *different meanings in the Complexity Test graphs than in the Speed Test graphs*. In the Complexity Tests the writer found that, when the difficult examples were presented, large deflections often occurred *before* the subject spoke—followed by additional deflections after she began speaking. This very seldom occurs in connection with easy examples or ordinary types of stimuli, since the latent

¹ To save space the tables giving the exact amplitude of the deflections indicated in the graphs have been omitted. The author will be glad to supply these tables to those interested. (Address, care University of Michigan).

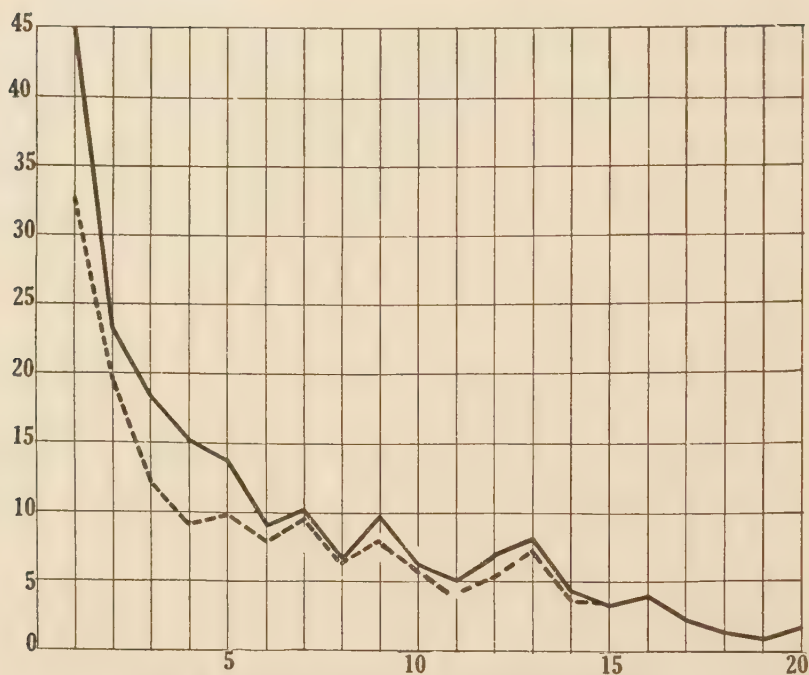


FIG. 5 Complexity Test 2 (12 cases) Difficult—Easy.

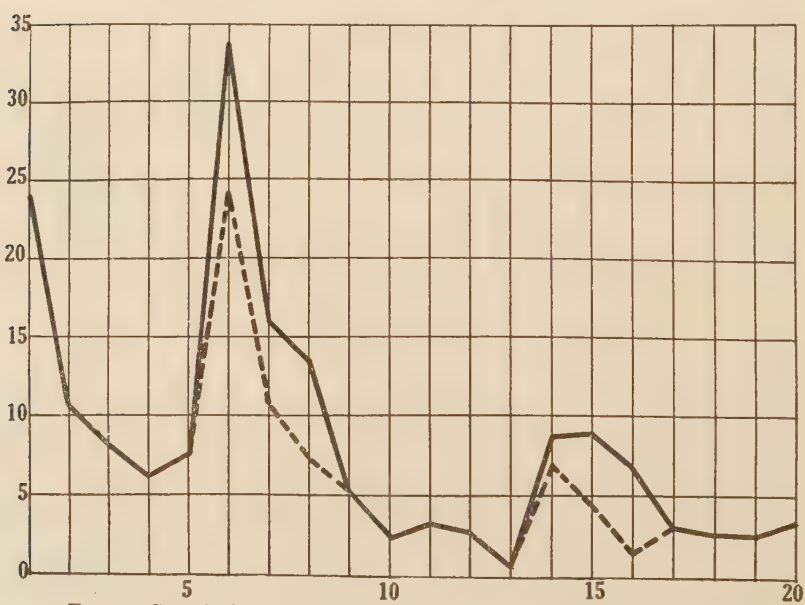


FIG. 6 Complexity Test 3 (15 cases) Easy—Difficult Alternating.



FIG. 7 Speed Test 1 (11 cases) 6-15 Fast, 1-5 and 16-20 Slow.

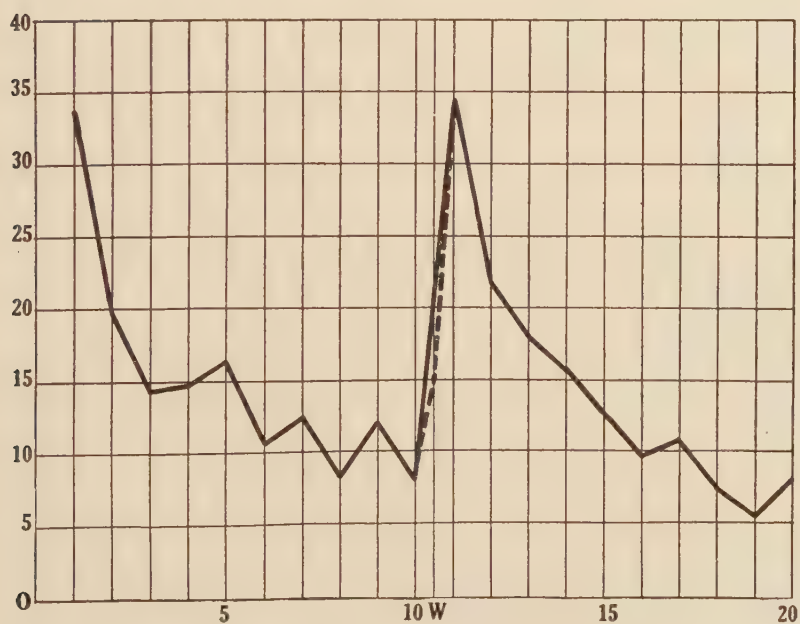


FIG. 8 Speed Test 2 (10 cases) 1-10 Slow, 11-20 Fast.

period of the reflex is three seconds and the subject's verbal response is usually given in less than that time. Thus, on the graphs for the Complexity Test, *the dotted lines indicate the average of deflections which occurred before the subject spoke*. They appear, of course, only for the most difficult examples.

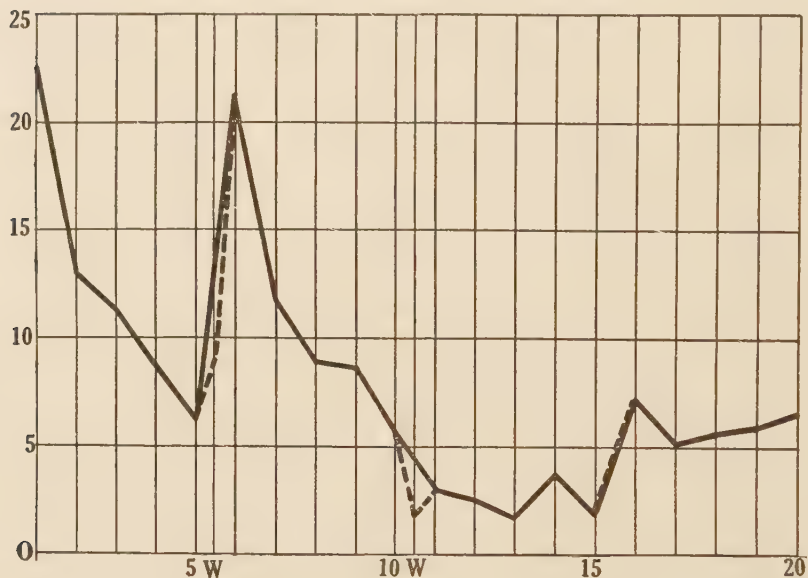


FIG. 9 Speed Test 3 (13 cases) 6-10 and 16-20 Fast, 1-5 and 11-15 Slow.

As has been stated, the procedure in giving the Speed Tests differed somewhat from that for the Complexity Tests. In giving the Speed Tests every change in rate was preceded by the warning signal, "Fast examples next," or "Slow examples next." With the Complexity Tests no warning signals were given.

"W" on the x-axis of the Speed Test graphs indicates a warning signal; thus, *the dotted lines on these tests indicate the average deflections following the warning signals*. On these tests, of course, no deflections occurred before the subject spoke.

2. MEAN DEFLECTION CURVES OF THE VARIOUS ADDITION TESTS

The graphical presentation of means brings out clearly some very consistent tendencies for all seven tests.

There are in the case of every test very large deflections (as compared with the mean for the whole test) on the first example, with a very rapid diminution in size of deflection between the first and the third to

fifth examples. These initial curves¹ are very similar on all tests and uniformly are parabolic in form. The fact that the initial deflections are notably less high on the practice test than on the later tests may, perhaps, be due to the fact that on the practice test the subjects knew all the examples were to be easy, whereas on the later tests they knew that difficulties were to be introduced somewhere. They might consequently be in a more apprehensive state during the later tests.

It has been noted by nearly all investigators that the first four or five deflections in an experiment usually seem to be markedly affected by something connected with the shift to a new situation. To what extent this is due to excitement, or tension, and to what extent to more purely local physiological and physical factors in the skin in or near the electrodes, is not known.

The Practice Test. In this test, where all examples are easy and of about equal difficulty, there is a rather rapid drop in amplitude of deflection up to Example 4. After this the curve shows a very slight but rather continuous downward trend throughout the experiment. There are no large deflections² for any examples after the first two or three. Such a gradual decrease during the course of an experiment has been noted by many experimenters. A reasonable assumption is that it indicates decreased activity of the sympathetic nervous system as the subject becomes adjusted to the experimental situation.³ The influence of fatigue on the physiological behavior of nerve, gland, and skin has also to be considered, although the influence cannot be great in an experiment such as this. Such factors as inhibition would tend to decrease rather than increase resistance. A factor which to the writer seems worthy of attention, though it has not often been mentioned, is the slight cooling of the skin through evaporation of the water in the electrodes. It is well known that cold increases the skin resistance. Some of the subjects said that their fingers felt a little cold at the end of the experiment.

Complexity Test 1. It will be remembered that in Complexity Test 1 the first ten examples are easy and of about equal difficulty; but beginning with example 11 they gradually increase in complexity up to example 20, which is extremely difficult. The five examples preceding 11 all give small average deflections of nearly equal amplitude with a slight tendency toward decrease. Example 11, the first to incorporate one two-digit number, seems only a little more complex than the preceding examples; yet there is a very striking increase in size of average deflection, rising far above any previous deflection after the second. Example 11

¹ The term "curve" in this and following discussions, always means "average deflection curve."

² By "large" in these discussions is meant larger than the mean for the 20 examples of the particular test in question, unless otherwise specified.

³ See Wechsler (46) p. 36.

does, however, represent the first increase in complexity that occurs in the test. Moreover, the subjects knew that it represented the first step in a series of increasing complexity. After Example 12, although the examples continue to increase in difficulty, the general trend in amplitude of deflection is toward a considerable decrease. Nevertheless the general level of amplitude of deflection for the difficult examples remains considerably above that for the easy ones (if we exclude the two initial ones).

We can hardly assume that the first two "complex" examples were actually harder than the following ones. The fact that 11 and 12 were almost always answered in less than three seconds, while the others took much longer, is objective evidence for this.

The general tendency, other factors being equal, for amplitude of deflection to decrease toward the end of the experiment has to be considered. However, in the tests such as Complexity Test 3 and Speed Test 3, where sudden changes are introduced at the 13th and 15th examples, the amplitude of deflections increases appreciably and remains at this relatively high level for at least three examples.

Evidently position toward the end of a series does not exclude increases in amplitude of deflection distinctly above the level of the preceding five or six examples if the stimuli are "stimulating" enough.

It is worth noting that the deflections which occur before speaking very closely parallel the total deflections, though at a somewhat lower level.

Complexity Test 2. Complexity Test 2 is the same as Complexity Test 1 reversed, except that the first five examples, instead of being very easy, are very complex (see p. 20). One should note that although the examples do not become materially easier until after the sixth, by far the most rapid drop in the curve occurs before this. A rapid drop at first seems to occur with any type of material.

The difficulty of the five initial examples in this test, as compared with their relative ease in the other tests, is distinctly reflected in the amplitude of the deflections. With the single exception of Example 5 in Speed Test 2 every one of the first examples of Complexity Test 2 gives deflections considerably larger than the correspondingly numbered example on any other test. These differences tend to become less, however, in proceeding from Example 1 to Example 5. In this test, as in Test 1, the deflections which occurred before the subject spoke very closely parallel the total deflections, and at an only slightly lower level.

It is of some interest to compare the examples which resulted in large deflections on Test 1 with the same examples in Test 2, (now in reversed position in the series). In Test 1, coming immediately after an easy series, Examples 11 and 12 gave very large deflections; in Test 2, coming after a more difficult series, these examples show very small deflec-

tions—smaller than those of any preceding examples in the series. Similar differences may be noted with other examples.

Complexity Test 3. It is worth observing that the deflection occurring at the first critical point in Test 3 is more than twice as great as the one which occurs at the first critical point in Test 1, despite the total mean deflections for the two tests being closely similar,¹ (9.47 mm. for Test 1 and 8.35 mm. for Test 3). It is true, of course, that the first critical point occurs considerably later in the series in the former test than in the latter. Nevertheless, if we judge by the rather slight amount of drop between Examples 6 and 11 in the curves of the Practice Test and of Test 1 the change in position certainly would be unlikely to account for any considerable part of the difference in amplitude of deflection. It seems reasonable to assume that the larger deflection in Test 3 is due in some way to the much greater difference in difficulty between the examples occurring at the critical point.

Speed Test 1. The first five examples of Speed Test I were "slow,"² and resulted in the usual preliminary deflection curve. Example 5 was followed by the warning signal, "Fast examples next." A marked rise in the curve is caused by the deflection following the warning. The deflection accompanying the first "fast" example (6) produces a still greater rise in the curve, though the new level is not much higher than that resulting from the warning signal. From Example 6 through Example 15 inclusive the "fast" examples were continued at a uniform rate of speed. The deflection curve for these examples is of a parabolic form rather strikingly like that of an inverted growth curve, or "curve of decay." We might call it here a "curve of adjustment," for the curve tends to flatten out as the subject becomes adjusted to the new situation presented by the increase in speed.³

Between Examples 15 and 16 the warning signal, "Slow examples next," was given. In this case, instead of the sharp rise which followed the "Fast examples" warning signal, there is actually a marked drop in the "deflection curve." The first "slow" example (16) causes a deflection only a little larger than the immediately preceding warning signal. In fact, all five of the terminal "slow" examples remain at about the same level—one distinctly lower than that for the immediately preceding "fast" ones.

Speed Test 2. In Speed Test 2 the first ten examples were given at the "slow" rate; the last ten at the "fast" rate.

The large total mean deflection (14.65) for Speed Test 2 has already

¹ Note also that Test 1 and Test 3 contain exactly the same examples, the only difference being arrangement in the series.

² See page 22.

³ See discussion on p. 38.

been discussed. Nevertheless, the behavior of the deflection curve for this test is of the same general type as that of the other curves. In this test there is an extraordinarily sharp drop in the "adjustment curve" corresponding to the fast examples, which instead of flattening out after the first five difficult examples as do the other adjustment curves, continues to drop with only slightly diminished rapidity throughout the next five. The continuous steepness of this curve may in part be due to the position of the last five examples at the very end of the test series. Here the factors of fatigue, boredom and inattention would be at their maximum and would probably operate to a greater extent with material such as this, which requires a certain degree of alertness, than in the case of easy examples. One would expect all the above-mentioned factors to facilitate a drop in the deflection curve.

Speed Test 3. In this test, Examples 6-10, 16-20 were given at the "fast" rate; 1-5, and 11-15 at the "slow" rate.

A very large increase in deflection follows the presentation of the first "fast" example (Ex. 6). For the following five "fast" examples there is an adjustment curve very similar, both in form and size of deflection, to the curve for the preceding five "slow" ones.

The curve for the last five examples of this test differs strikingly from the adjustment curves always observed in similar stimulus-situations in the present experiment. In fact, it is apparently not an adjustment curve at all. The general trend here is actually in the direction of increased amplitude of deflection. This test, however, unlike the others, was taken by several of the subjects just before one of their classes which met in an adjoining room. On several occasions the test was not quite finished at the beginning of the class period. The students could be heard entering the classroom, and the subject was aware that the class was about to begin, or had begun. This produced a noticeable state of tension in some of the subjects, which apparently was reflected to some extent in the amplitude of their deflections.

Still it must be admitted that the difference in responses to the last five examples of this test and the last five examples of Test 2 is an anomaly for which the writer has no wholly satisfactory explanation.

3. GENERAL CHARACTERISTICS OF THE MEAN DEFLECTION CURVES

It should be noted that in each of the three Complexity Tests the curve for deflections occurring before the subject spoke closely parallels the curve for total deflections, at a not very much lower level. It would appear from this that the large deflections for the difficult examples are due chiefly to other factors than the muscular tensions required in speaking, but that this latter factor, or some physiological changes accompanying it, contributes an added increment to the amplitude of deflection.

In the Speed Tests, the deflections corresponding to warning signals invariably show the same tendencies as the deflections for the immediately following examples, though only in the case of Speed Test 1 is the resemblance close, and in every case the actual (critical) example gives a larger deflection than its warning signal. As has been said, the warning signals require no oral response, while the actual examples did. Judging from the results in the Complexity Tests the greater deflections for the actual examples may be due in part to factors connected with the verbal response. On the other hand it would not be surprising if the examples were, *per se*, stronger stimuli than the warning signals.

Deflections at Critical Points. An invariable characteristic of all the mean deflection curves is the very large increase (as compared with the mean of the easy or slow examples) in amplitude of deflection which occurs at what the writer, following Wechsler, has called *critical points*. These critical points represent two kinds of situations: (*a*) the initial examples of a test, either easy or difficult (Here the increased deflections are apparently in some way connected with adjusting to the shift to the test situation); (*b*) the initial examples of a series which is distinctly more difficult (complex or fast) than an immediately preceding series. In the two tests, Complexity Test 3 and Speed Test 3, where two critical points aside from the beginning occur, the last critical point is accompanied by a much smaller increase in deflection than the others. The deflections accompanying the beginning examples and the deflections accompanying the first critical point following these are almost invariably at least twice the size of the mean deflection¹ for the entire distribution. On the other hand the deflections corresponding to the terminal (third) critical point are about twice the size of the average for the five examples immediately preceding them, but are smaller than the mean for the entire distribution.

Interpretation of Critical Points. As far as deflections corresponding to critical points are concerned, the results for all tests, whether Complexity or Speed, are strikingly similar.

Is it simply a sudden shift in the stimulus situation which is responsible for the increased deflections? Apparently not, for when instead of a sudden shift in the direction of increased speed or complexity there is an abrupt shift in the opposite direction—toward decreased complexity or speed—there is in the mean deflection curves an invariable and distinct decrease in amplitude of deflection; this decrease, however, is in no case strikingly great.

There has been some confusion in regard to this tendency of psycho-

¹ The deflection occurring at Example 11, Complexity Test 1, is between $\frac{1}{3}$ and $\frac{1}{2}$ again as large as the mean for the entire distribution. Other deflections at critical points are as stated above.

galvanic deflections to decrease rather than increase with sudden shift of the stimulus situation in the direction of greater ease of adjustment.

Such a tendency is perhaps more or less implied by the "conation" theory and to some extent by the "emotion" theory of the causation of the p.g.r. Nevertheless, it sometimes has been assumed that a situation where the subject experiences relief from tension or difficulty will be accompanied by large p.g. deflections. Bartlett, (3, p. 50) for example says that one of the four typical situations in which the p.g.r. is generally agreed to appear is "when a task is concluded with satisfaction or relief (the relaxation of our experiments.)"

The results obtained by the present writer are not wholly contradictory to this view, for here the drop in the deflection curve at points of decrease in difficulty (or speed) represents the difference between the deflection corresponding to the last difficult (or fast) example and the deflection corresponding to an easy example presented 30 seconds later. Any deflection occurring as an expression of relief would probably have occurred during the 30 second interval, and hence would not be recorded in the deflection curve. If occurring immediately after the completion of the example, the deflection might perhaps have been recorded in summation with the deflection for the difficult example.

As a matter of fact, the writer noticed that moderate and sometimes large deflections not infrequently occurred after the completion of an example. In a number of cases these were the result of an audible sigh or yawn. Unquestionably the drawing of a deep breath is usually accompanied by a deflection of considerable size. It seems to the writer that psychogalvanic deflections occurring as expressions of relief or satisfaction may for the most part be due either to an actual *or suppressed* sigh or deep breath, either of which would presumably involve increased activity of the sympathetic.

This deep breathing seems to be rather a hangover from or "last gasp" of the tension situation than a characteristic of relief or relaxation.

At any rate, the results supply evidence for the view that when a relaxation situation is separated from a tension situation by time enough to allow the tension hangover to subside, the former situation shows smaller deflections throughout than does the latter.

Characteristics of Curves of Adjustment. Another striking characteristic in some degree common to all the deflection curves is what has been called in this paper the curve of adjustment. By "curve of adjustment" is meant a characteristic parabolic tendency of the deflection curve corresponding to a series of examples following a critical point.

Even though the examples following a critical point continue at an equal or higher level of difficulty and speed, there is usually an immediate and considerable drop in the deflection curve. The curve generally

drops rapidly, though at a slightly decreasing rate, for the first two or three examples following a critical point and then shows an increasing tendency to flatten out.

These curves of adjustment show a considerable resemblance to inverted growth curves, or curves of decay. The resemblance to a growth curve is particularly marked in the deflection curve corresponding to Speed Test 1, Examples 6-15 inclusive.

Factors Affecting Adjustment Curves. Although the deflection curve regularly tends to drop rapidly after the critical example in all the tests, it should not be concluded that complexity and speed are factors only at the critical points. As has been seen, the adjustment curve for Examples 11 to 20 of Complexity Test 3, where the examples are of increasing difficulty, shows much less of a drop than any of the other adjustment curves and is obviously so affected by factors due to the continuing complexity of the examples as to show only in a most general way the typical characteristics of an adjustment curve. Moreover, the deflection for every one of the difficult examples is considerably greater than that for any of the easy examples after the two or three preliminary ones.

Adjustment after a critical point seems on the whole to be easier and more rapid in the case of the Speed Tests than it is in that of the Complexity Tests.¹ No doubt this is due in one way or another to the differences in the nature of the material. *A priori*, one would expect that adjustment would be easier in the case of the Speed Tests where success largely depends on alertness to the stimuli (and probably to some extent on ocular accommodation) rather than on the more complex mental processes involved in the Complexity Tests. The writer has already noted (p. 27) that the adjustment curves for Speed Tests 1 and 2 are accompanied by a drop in number of errors made by the subjects.

Meaning of Adjustment Curves. Only a tentative explanation of the meaning of the "adjustment curves" can be given. In the writer's opinion these curves represent chiefly a central nervous phenomenon, and are primarily the result of (central) adaptation to the stimulus situation. As the adaptation proceeds one would expect sympathetic nervous activity to decrease. However, the curves may well be to some extent influenced by local skin organ changes.

Veraguth (41) and Grünbaum (17a) have noted that when one type of stimulus has caused exhaustion of the p.g.r., the phenomenon will sometimes reappear in full strength when a new type of stimulus is introduced. At the end of a number of the writer's sittings which ended with "difficult" or "fast" examples that had ceased to be accompanied by large deflections, a bell was rung 30 seconds after the completion of the

¹ With the exception noted on p. 36.

last example. This was with few exceptions followed by a large deflection—often as large as, or larger than, the deflections which had accompanied critical points near the beginning of the experiment.

In other cases the terminal “difficult” or “fast” example was followed successively by the stimulus words “kiss” and “love.” Deflections following one or both of these words were usually approximately as great as or greater than deflections accompanying critical examples placed early in the series. In spite of the fact that the bell and “kiss-love” stimuli were used in only 5 or 6 cases each, the results strongly suggest that the “adjustment” curves are not primarily due to physiological exhaustion of the organs responsible for the p.g.r.

The writer is indebted to Professor C. H. Griffitts of the University of Michigan for suggesting the wisdom of considering the possibility that the form of the adjustment curves may be due to a progressive approach of some of the organs responsible for the p.g.r. toward their maximum limit of functioning.

Inasmuch as the apparent resistance of most subjects decreases throughout the experiment, the galvanometer deflections are really superimposed on a general curve of a form uncertain, but perhaps generally parabolic.

If this general curve represents a progressive approach of certain organs—let us say sweat glands—toward their physiological limit of activity, then the deflections corresponding to the later stimuli of a series might appear to be small simply because they were measured from a starting point close to the possible limit of sweat-gland activity.

It seems to the writer unlikely that this criticism applies to any appreciable extent to the present experiment. In the first place, the stimuli used in this experiment—and indeed those used in nearly all laboratory experiments—are extremely “mild” as compared to many of the stimuli of real life.

Waller (44) has stated that p.g. responses of an individual during a German air raid were at least 200 per cent changes on initial resistance, while the responses ordinarily obtained in the laboratory are at most 10 per cent changes. Waller comments that he could not reproduce these large changes artificially by any means he cared to employ.

It seems extremely unlikely *a priori* that in an experiment of this kind the sweat glands or other organs concerned with the p.g.r. would approach very close to their extreme limit of activity. Even taking a cumulative effect into account, one must remember that there were only twenty stimuli and that there was considerable opportunity for physiological recovery of the skin organs in the interval between stimuli. Moreover, we have the direct evidence of the occurrence of large deflections when a new type of stimuli was introduced at the end of a series.

In following up other strands of the argument one aspect of the question has been left for more or less at loose ends. In any case, it may be argued, the changes in skin-organ activity responsible for the p.g.r. should be measured from a stable point of reference and the most satisfactory point of reference would be the condition of these skin organs at the beginning of the experiment.

No doubt it would have been desirable to let the line of light return of its own accord to zero before applying a new stimulus. Then we might have assumed that at the beginning of each deflection the skin organs were always approximately at an equal distance from their physiological limit of functioning so far as their effect on the p.g.r. is concerned. It would, however, have been impracticable to wait for this spontaneous readjustment, which often fails to occur during a considerable period of time. Furthermore, long waits would in themselves have led to increased suspense and nervous tension in many subjects.

It should be remembered, also, that the writer did maintain a constant point of reference in measuring the deflections, though this point of reference was not a physiological one. The current in the circuit was kept approximately constant throughout the experiments. Consequently, when the apparent resistance of the subject decreased during the course of a sitting, the extra-somatic voltage was proportionately decreased. If, after a deflection, the line of light did not spontaneously return in 30 seconds to within 20 mm. of the zero point on the scale the voltage was altered so as to bring the line back within the required limits.

The question remains, of course, as to the proper method of keeping the current constant. The Wechsler method used in this experiment is perhaps, as Davis (7) suggests, defective; but at least it may be assumed that it works roughly in the right direction. And if it is roughly correct, its defects could hardly be responsible for the general shape of the adjustment curves.

Still, the writer is willing to admit that some constant uncontrolled factor in the experimental technique—perhaps some sort of electrode effect such as the action of the saline solution on the skin—may possibly be responsible for the adjustment curves. All that can be said is that the available evidence points to another explanation.

CHAPTER IV

INDIVIDUAL AND INTROSPECTIVE RESULTS

1. SUMMARY OF INDIVIDUAL RESULTS

A comparison of individual differences at the critical points of each test was made as a check on the mean deflection curves.¹

For each subject, on every test, the difference was computed between the average deflection for the three examples just preceding and the three examples immediately following each critical point. In 81 out of 87 cases the three examples following the critical point were accompanied by larger average deflections than the three examples preceding it. That is to say, in 93 per cent of the individual cases an abrupt increase in difficulty or speed was accompanied by an increase in amplitude of the deflection.

Computed in the same way, the data show that an abrupt decrease in difficulty or speed resulted in smaller average deflections than those preceding it, in 75 out of the 78 cases (96 per cent).

The average deflection (for three examples) at the first critical point² was in a majority of cases above the mean of the subject's deflections for the whole test. Obviously, the results for the individual cases are very strikingly consistent with the mean-deflection curves as far as deflections at critical points and points of decreased difficulty of adjustment are concerned.

In regard to the form of individual deflection curves the results cannot be presented statistically, but some representative cases will be described.

Similarity of Group and Individual Deflection Curves. Deflection curves for individual cases are, of course, less regular in form than are those for the means. The adjustment curves clearly take the typical inverted "growth curve" form in a considerable number of cases, but a good many individuals vary from this in one way or another. With some subjects the curve falls rapidly from the beginning to the end of a particular level of speed or difficulty; in other cases, it drops very slowly. Some tendency for the curve to drop soon after the critical point is usually evident, however.

The accompanying graphs (Fig. 10) will give an idea of the general run of individual curves.

The graph for Subject 20, Complexity Test 2, (Fig. 10a) represents an

¹ The five preliminary examples of all tests were excluded in these comparisons.

² That is, the first critical point beyond the five preliminary examples.

individual who gives very large and very irregular deflections. That is, a good many deflections of considerable size occur at other than the critical points. Although the "adjustment curve" is somewhat distorted by the large spontaneous deflections, it may still be detected in broad outline. Similar results were obtained with this subject on other sittings.

Consistently Large Deflections in an Individual. The three deflection curves for Subject 7, Complexity Test 1, Speed Test 1, Complexity Test 3 (Figs. 10b, 10c, 10d) represent an individual who consistently gives deflections somewhat larger than the average. She shows, however, a less marked tendency than Subject 20 to give spontaneous deflections. In fact, her curve for Complexity Test 3 (Fig. 10d) is remarkably smooth and of low level, except at the critical points, where very large deflections occur. The adjustment curves are unusually steep.

In Complexity Test 1, (Fig. 10b) Subject 7 also gives a curve remarkably similar to that of the mean curve for the test—except for an extraordinarily large deflection corresponding to Example 16. The writer has the following note written immediately after the completion of this test: "On the 16th question, the subject gave three answers, discovering an error each time. *Before* each answer there was a large deflection. Between the second and third answer the subject burst out, 'What's the matter with me. I can't seem to get this.' The third answer was followed by several large spontaneous deflections." A number of similar experiences could be cited to show that an obvious struggle to solve the example resulted in large and repeated deflections. In fact, there was hardly an exception to this.¹

It is interesting to note that the subject on completing this test remarked, "I never *could* do mental arithmetic!" After completing Complexity Test 3, however, she said that while she would say off-hand that she disliked arithmetic, she had never had any trouble with it. Her score on the Monroe Arithmetic Test, given later, was third from the highest out of a group of nineteen. This is of some significance in view of some results to be reported later in this paper.

This subject's curve for Speed Test 1 (Fig. 10c) is somewhat similar to her preceding ones. Except for a large spontaneous deflection at Example 18, the curve is remarkably regular and typical. The subject reported that when Example 18 was presented she had been inattentive and then suddenly "came to," thinking she was giving the wrong answer. The latent period for this example was a little short (between one and two seconds) and it is not unlikely that the deflection is in part due to a slight muscular start or twitch.

¹ It is worth observing that the mean deflection curve also shows a rise at Example 16. Considering the small number of subjects taking this test, Subject 7 no doubt contributed largely toward causing this rise.

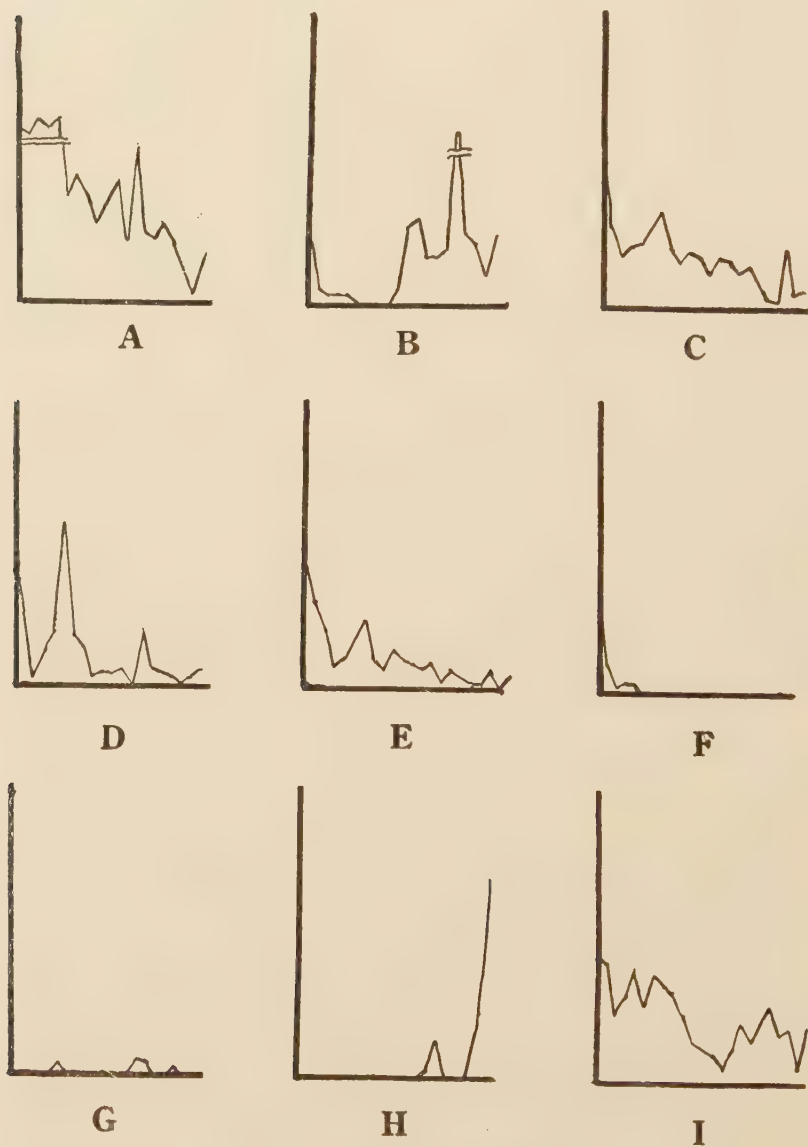


FIG. 10 Graphs of Individual Results

Subject 1, Speed Test 1, (Fig. 10e) gives mean deflections of about average amplitude as compared with the group. This curve requires no comment.

Consistently Small Deflections in an Individual. Subject 21, Complexity Test 2 and Complexity Test 3 (Fig. 10F and Fig. 10G) is included as an example of an individual who consistently gave very small deflections or none at all. Nevertheless, some deflections do occur at the critical points and there is evidence of adjustment curves not very different in form from those of subjects who give average or large deflections. This subject stated, "I'm not at all excitable. People criticize me because I never get excited about anything." She said that she "loved" to do arithmetic and had almost decided to major in mathematics. The only time she felt the need of effort, she stated, was when the first one or two difficult numbers on Test 2 appeared. "I felt a little appalled at the size of the numbers."

Sudden Appearance of Large Deflections in an Individual. Subject 10, Complexity Test 1, (Fig. 10H) is interesting because she gave no deflections at all until she met some particular difficulty, whereupon she gave very large ones. Up to Example 15 she apparently had no difficulty whatever. She hesitated a moment before giving the answer to this example. A deflection of 5 mm. occurred before the answer was given. Immediately after answering she said, "That's wrong—no, that's right." An additional deflection of 5 mm. followed this statement. The subject experienced no further difficulty in answering until she reached Example 19; here she pondered a long while before replying. The major part of the deflection occurred when she gave her answer.

To Example 20 she responded almost immediately, "One million . . ." Then there was a long pause followed by a 48 mm. deflection. She then made several unsatisfactory attempts to answer, each one followed by a considerable deflection, until the galvanometer line ran off the scale too far to return. After the test she remarked, "That last one certainly was a sticker." She said that she felt little effort or excitement until she got stuck and couldn't do the last example. Then she became irritated. "Ordinarily," she said, "I don't get excited and people think I'm unusually self-possessed, but when things really go wrong I get very much upset."

Curves Deviating from the Usual Form. The graphs which have been included so far are a fair sample of those for the entire distribution, but it would be misleading not to state that there were a few curves which departed considerably from the usual tendencies. The graph for Subject 17, Speed Test 3, (Fig. 10I) represents probably the most anomalous of those which the writer included in his results.

This subject was less coöperative than most and several times expressed her boredom at taking part in the experiment. During the test she

was obviously restless and inattentive. After answering Example 14 incorrectly she said, "I'm sorry, I guess I wasn't paying attention." And after Example 20 she remarked, "I didn't see that one." The curve is probably more expressive of her irritation and impatience than it is of her reaction to the experimental changes, yet there was no direct evidence of the deflections being affected by sighs or muscular movement.

On the whole, despite considerable differences among subjects the individual curves very consistently confirm all of the main tendencies noted in the mean-deflection curves.

2. COMPARISONS OF INDIVIDUAL RESULTS

Consistency of Deflections in Different Sitzings. A rough check was attempted by the writer on the reliability of the electrical measures obtained on successive tests of the same subject. First a comparison was made of each subject's rank in the group in regard to the mean amplitude of her galvanometer deflections on different sittings. The rank-difference correlations of mean amplitude of deflection of one sitting compared with another (excluding the practice sitting) were as follows:

First Sitting with Second Sitting— $\rho = +.523 \pm .107$ (21 cases)

Second Sitting with Third Sitting— $\rho = +.569 \pm .116$ (17 cases)

First Sitting with Third Sitting— $\rho = +.464 \pm .131$ (18 cases)

It should be remembered that the subjects took a different test at each sitting, so that they were being tested with similar stimuli, not with a repetition of the same stimuli. Moreover, the sittings were given at rather widely separated intervals, varying from a little less than a week to nearly three weeks in the case of different subjects. This would presumably tend to reduce the size of the correlations.

As it is, the writer's results are about the same as those found by Wechsler and Jones (46a)¹ between deflections corresponding to similar stimuli on different trials with the same subjects, and are not very much lower than those found by Smith (36, p. 122) and by Lauer (25) between deflections corresponding to repetitions of the same stimuli (Smith $+.65$; Lauer $+.62$).

Any correlation involving so few cases as those used in the present experiment is of course exceedingly unreliable. Nevertheless, the similarity of the three correlations is evidence that, probably, they are not wholly the result of chance factors. It seems safe to assume that they show at least a significant tendency for subjects to maintain (for similar stimulus-material) a fairly consistent level of amplitude of deflection on different sittings.

¹ These writers found that correlations between deflections following stimuli imposing similar tasks averaged $+.50$.

Initial Resistance in Different Sitzings. Another measure which lends itself well to individual comparison is initial resistance, that is to say, the subject's apparent resistance in ohms just before the beginning of the experiment. Rank-difference correlations of initial resistance (excluding the practice sitting) give the following results:

First Sitting with Second Sitting— $\rho = +.473 \pm .175$

Second Sitting with Third Sitting— $\rho = +.126 \pm .136$

First Sitting with Third Sitting— $\rho = +.394 \pm .149$

Apparently initial resistance, like amplitude of deflection, tends to some extent to remain on a similar level for each subject from one sitting to another. The correlations, however, are so low as to be of doubtful significance.

Coefficients of Variation in Different Sitzings. Coefficients of variation of the same subjects on different sittings give distinctly lower correlations than do the other two measures: Arranged as above these are $+.057 \pm .166$; $+.249 \pm .063$; $+.262 \pm .164$. These correlations are so low, in fact, that their significance is negligible. Why this is so can only be surmised. However, as has been pointed out, the measure of variability undoubtedly differs more from test to test than do the means, and is probably more affected by differences in arrangement of test material, as well as by changes in the subject's mood. The measure of central tendency may perhaps reflect a more underlying and constant factor of the individual's make-up.

Comparability of Different Subjects' Deflections. In the present experiment, it is true, only 19 cases were available for comparison and the various addition tests which served as stimuli for the deflections were not always precisely comparable for the different subjects. Most of the subjects were tested several times, but the nature of the various tests is so different that combining their deflection results is a questionable procedure. Nevertheless, for curiosity's sake, rough correlations were made between each subject's average amplitude of deflection.

Comparison of Results for Different Subjects. In psychogalvanic experiments there are many pitfalls in the way of comparison of the results for different subjects. Even granting that the differences in initial resistance are satisfactorily compensated by the potentiometer (and this is somewhat doubtful, cf. p. 3ff.) one cannot be sure that individual differences in amplitude of deflection are not in many cases due to local differences in the physico-chemical make-up of the skin of the hands, or in the distribution of sweat glands and capillary blood vessels, rather than to differences in the activity of the sympathetic nervous system. So far as the writer is aware there exist no determinations of individual differences in these local skin organs.

Individual comparison is made more difficult in the present experiment by the small number of cases who took each test and by the difficulty of comparing a subject's scores on different tests, owing to the differences in test material. Yet it was thought worth while to attempt certain correlations in view of the general consistency of the results and for the purpose of comparison with the findings of other experimenters. Comparison of average galvanometer deflections derived from the different tests is made more justifiable by the fact that the group means of the mean deflections are closely similar, as has been seen, for all tests except Speed Test II (see p. 26.) The means for the different sittings (regardless of type of test) are also remarkably similar; 9.77 mm. for the first sitting; 9.69 mm. for the second sitting; 9.33 mm. for the third sitting; and 8.37 mm. for the fourth sitting. Apparently neither the type of test taken nor the sitting during which it was taken makes much difference in the mean results of the group.

Method of Comparison of Individuals. In order to render the results more comparable, all the cases of Test II (which gave the exceptional group mean deflections) were left out of the calculations. With this exception, the mean deflection of the combined tests taken by each subject was found and taken as the score used in the correlations.

Twenty of the writer's subjects were given the following test and questionnaire on two successive days immediately after the completion of the galvanic tests. The subjects were tested as a group under ordinary classroom conditions.

First, the group was given Monroe's Standardized General Survey Arithmetic Test, Scale I (Form 1, Tests 1 and 2) and Scale II. In working with the results the writer used the combined scores of the three tests—giving equal weight to each. This seemed the fairest method of combination for the present purpose, since over two-thirds of the examples on the writer's deflection-tests are similar in type to Monroe's Tests 1 and 2. A rough correlation by the method of unlike signs shows an estimated r of about .70 between the scores on Scale I and II and estimated r 's of over .90 for either scale correlated with the composite score.

The following questionnaire was also given:

QUESTIONNAIRE I

1. Underline the word that most nearly expresses the true answer to the following questions.

(a) Do you like mathematics as a whole?

Like very much Like Like fairly well Slight dislike Strong dislike.

(b) Do you like arithmetic as a whole?

Like very much Like Like fairly well Slight dislike Strong dislike.

(a) Do you like to do addition?

Like very much Like Like fairly well Slight dislike Strong dislike.

2. How would you class yourself on the following scale in regard to your general temperament as compared to the average of people you know? Answer both (a) and (b).

(a) Very excitable Rather excitable About average Rather calm Very calm.

(b) Very nervous Rather nervous About average Rather calm Very calm.

3. Do you tend to get nervous or "fussed" on school examinations? Answer both (a) and (b).

(a) Very nervous Rather nervous Not very nervous Rather calm Very calm.

(b) Usually Often Sometimes Seldom Almost never.

Use of the Self-Ratings. The subjects' self-ratings in regard to their liking for mathematics as a whole, for arithmetic, and for addition were in most cases very similar and in all cases were on the same side of the median of the five-point scale.

In working out the correlations only the addition ratings were used.

The two questions in regard to general temperament were also answered in very similar fashion and in only one case involved a transfer to the other side of the median of the five-point scale. In calculating the correlations, the excitability ratings alone were used. Apparently "Nervousness" and "Excitability" mean about the same thing to most of the subjects.

Answers to the last two questions (3a and 3b) also corresponded closely in their place on the scale. In preparing the answers for correlation a composite score was formed by averaging the positions of the two answers on the five-point scale.

There was also a very close correspondence between the ratings (excitability) for general temperament, and the composite ratings for nervousness-on-examinations. In only two cases was there a transfer to the other side of the median.

For all the questionnaire questions there were of course a great many tied responses. There were also a number of tied cases in the arithmetic scores. In view of this, it was impossible to calculate rank-difference correlations where these tests were involved. The best that could be done was to work out approximate correlations by the method of unlike signs.¹

¹ This method is described by Otis, A.S., *Statistical Method in Educational Measurement*, New York, World Book Company, 1925, pp. 213-214. "This method takes account merely of the proportion of cases in which an individual stands above the median of the group with respect to one measure and below the median of the group with respect to the other." Otis gives a table (p. 297) showing the coefficient of correlation (r) corresponding to various proportions (u) of unlike signs.

Significance of the Correlations. The writer does not wish to attach much significance to any of these correlations, yet the consistency between them is great enough to be worth mentioning. The correlations of the test and questionnaire results with each other are sufficiently high and consistent to suggest that they have a fair degree of validity. More in-

TABLE III
APPROXIMATE (UNLIKE-SIGN) CORRELATIONS OF TEST-QUESTIONNAIRE
RESULTS WITH EACH OTHER

Items Correlated	Percent of Unlike Signs (u)	Estimated r	Number of Cases
Arithmetic-liking with arithmetic score	.23	+ .75	18 ¹
Test-nervousness rating with arithmetic score	.71	- .61	18
Test-nervousness rating with arithmetic liking	.59	- .28	18
Excitability rating with arithmetic score	.59	- .28	18
Excitability rating with arithmetic-liking	.55	- .16	18
Excitability rating with test-nervousness rating	.33	+ .51	18

¹ 18 subjects took both the test and questionnaire. One took the test but not the questionnaire, and one the questionnaire but not the test; i.e., two of the 20 subjects did not answer both the test and the questionnaire and their results are excluded from the above table. This explains the apparent discrepancy with Table IV in regard to number of cases.

teresting is the fact that the correlations of arithmetic score with average deflection and of test-nervousness rating with average deflection, though rather low, are consistent with one another and with the test questionnaire correlations.

In addition to the above correlations, an attempt was made to correlate initial resistance with test questionnaire results and coefficient of variability with test questionnaire results. Both these measures yielded low and inconsistent correlations.

A Suggestion in Regard to Comparing Different Subjects. It has occurred to the writer that in tests of the kind employed as stimuli in these experiments the use of a ratio between amplitude of deflections at critical points and amplitude of deflections caused by easy examples might give a measure which would remove many of the objections to comparing the

TABLE IV
APPROXIMATE (UNLIKE-SIGN) CORRELATIONS OF TEST-QUESTIONNAIRE
RESULTS WITH AVERAGE AMPLITUDE OF DEFLECTION

Items Correlated	Percent of Unlike Signs (<i>u</i>)	Estimated <i>r</i>	Number of Cases ¹
Arithmetic-liking with average deflection	.53	+ .09	19
Arithmetic score with average deflection	.66	- .43	19
Test-nervousness rating with average deflection	.37	+ .40	19
General-excitability rating with average deflection	.53	- .09	19

¹ See note following Table III.

deflections of different subjects. One might expect differences in nervousness or tension to be most pronounced at the critical points and less pronounced in the case of easy examples. Rough calculations based on the writer's tests seem to indicate some correspondence between test-nervousness ratings and amplitude-of-deflection ratios; but the correspondence may be wholly illusory, as a satisfactory comparison of this kind is impossible with the data of the present experiment. The critical points of the different tests are not comparable with each other and there are very few subjects taking any one test.

As a net result, the individual correlations suggest that research concerning individual differences in efficiency of test performance and in attitude toward tests may be furthered by means of measurements with the p.g.r. Little importance should be attached to the present correlation results aside from the grounds they give for hope of success in future experiments.

3. INTROSPECTIVE REPORTS OF SUBJECTS

So much ink has been devoted to the question whether affective tone, conation, or something else is the psychological correlate of the p.g.r. that it seemed well to obtain some sort of introspective record from the subjects. This was done by means of a questionnaire given to the same subjects who answered the first questionnaire,¹ and on the same occasion. Possibly it would have been better to have each subject answer these or similar questions immediately after every test. It seemed advisable, however, to obtain the individual's spontaneous report of her feelings at these times rather than repeatedly to subject her to an inquisitorial process of which the anticipation might influence her affective state. Moreover, it seemed quite likely that the residual impression left on completing the test series would as accurately represent the general average of the subject's feelings as the sum of three or four separate introspections. The residual impression probably is comparatively free from the influence of irrelevant factors in the immediate situation which might have affected earlier introspections.

In reproducing the questionnaire, the number of *yes* and *no* answers to each question has been inserted by the writer within parentheses.

QUESTIONNAIRE II²

I

Please answer *yes* or *no* to as many of the following questions as you honestly can.

When taking the tests (omitting to consider the first test) did you usually feel—

- a. Calm during the easy part of the test, but excited or nervous while doing the difficult examples? (No, 7; Yes, 9; Total, 16.)
- b. Calm while doing the "slow" examples, but excited or nervous while doing the "fast" examples? (No, 4; Yes, 12; Total, 16.)
- c. Excited or nervous when the difficult examples first appeared, but calm while doing the rest of the difficult examples? (No, 4; Yes, 13; Total, 17.)
- d. Excited or nervous when the examples were first speeded up, but calm while doing the rest of the "fast" examples? (No, 3; Yes, 14, Total, 17.)
- e. Calm during the entire test? (No, 16; Yes, 1; Total, 17.)
- f. Excited or nervous during the entire test? (No, 15; Yes, 0; Total, 15.)
- or g. Were your feelings so variable on different tests that it is impossible or very difficult to tell how you usually felt? (No, 11; Yes, 4; Total, 15.)

¹ This questionnaire was answered by the 18 subjects mentioned in Table III.

² It will be noted that some subjects have not been wholly consistent in their answers to questions IIb and IIc, as compared with IIa and IIc.

In these questions, if you feel that the word "excited" best expresses your feelings, underline it. If you feel that the word "nervous" best expresses your feelings, underline both. If neither word expresses your feelings with fair accuracy, do not underline either.

II

Please answer *yes* or *no* to as many of the following questions as you honestly can.

REGARDLESS of whether you felt calm or excited:

- a. Did you, on the whole, have a feeling of greater effort while you were doing the difficult numbers than when you were doing the easy ones? (No, 1; Yes, 16; Total, 17.)
- b. If you do *not* feel that the word "effort" expresses your feelings, would it be correct to say that you felt a greater "alertness" while you were doing the difficult examples? (No, 2; Yes, 9; Total, 11.)
- c. Did you on the whole have a feeling of greater effort while doing the "fast" examples than when doing the slow ones? (No, 7; Yes, 9; Total, 16.)
- d. If you do *not* feel that the word "effort" expresses your feelings would it be correct to say that you felt a greater "alertness" while you were doing the "fast" examples than when you were doing the slow ones? (No, 1; Yes, 12; Total, 13.)

Interpretation of the Questionnaire. As might be expected, Questionnaire II shows considerable difficulty on the part of the subjects in defining their conscious states. In Part I, five subjects consistently preferred the term "nervous" to the term "excited." Two subjects consistently indicated the opposite preference. One subject preferred the word "excited" for the Complexity Tests and the word "nervous" for the Speed Tests. Two subjects consistently underlined both "excited" and "nervous." Nine subjects underlined neither word, showing, presumably, that neither very satisfactorily expressed their conscious state, although these omissions may have been due to carelessness or indifference.

Conversation with the subjects indicated that most of them felt that both the words "nervous" and "excited" expressed to some extent their conscious state during the "critical" points of the test, but that neither was wholly satisfactory. To most of them "nervous" and "excited" seemed to be more or less synonymous terms.

It is interesting to note that while the majority of the subjects said that they felt more "nervous-excitement" in general while doing difficult and "fast" than while doing easy and "slow" examples, the percentage of agreement is rather low for the Complexity Tests, although fairly high for the Speed Tests. There is, however, a better agreement in regard to the subject's conscious states during the "critical" points. One finds a very close correspondence between introspective report of "nervous excitement" and sudden change in stimulus situation. The same re-

lation holds, of course, between introspective report and the largest galvanometer deflections.

Points of General Agreement. There is a tendency indicating that a number of subjects felt calmer after the initial change in stimulus situation, even though stimuli continued at the more difficult level, or faster rate of presentation. These reports might be expected in view of the curve of adaptation or adjustment shown in the records of the galvanometer deflections (p. 38-39.)

The almost unanimous agreement of the subjects that they usually felt neither particularly calm nor particularly excited during the *entire* test is interesting. At least we may say with some certainty that, judged by their introspective reports, they "felt different" during the critical parts of the performance than elsewhere.

In Part I of Questionnaire II most of the subjects regardless of their feelings of excitement or calm report an increased feeling of "effort" or "alertness" while doing the difficult and the fast examples. It is worth noting that the majority of them prefer the term *effort* when speaking of the Complexity Tests and the term *alertness* when speaking of the Speed Tests. A number of subjects seem undecided between "effort" and "alertness."

The great majority of the subjects, then, report both "emotion" (or, at least, nervous-excitement) and "conation" at the critical points of the tests. Very consistently, and with only one exception, the subjects agree that they "felt differently" at the critical points.¹

The writer regrets that he did not include in the questionnaire a reference to "tension" or "feeling tense" as a conscious accompaniment of the p.g.r. Several of the subjects spontaneously used this term in describing their feelings to the writer on the completion of the experimental sittings and one subject added a note to her questionnaire saying that she felt that "tension" expressed her feelings better than any of the questionnaire terms, at least for the Speed Tests. A number of considerations have since led the writer to conclude that tension may be a more satisfactory term than those used in the questionnaire.

4. INTERPRETATION OF INTROSPECTIVE RESULTS

Possible Interpretations of Introspective Reports. If one were so disposed, it might be possible to interpret the writer's results in terms of affective tone or conation. Obviously the points of suddenly increased complexity, or speed, might with many subjects result in some sort of emotional disturbance; with equal or greater likelihood these changes might result in intensified conation.

¹ Introspective reports were in many cases also obtained informally from the subject immediately after each test taken. They agree closely with the above results.

It would be difficult to give very good reasons for preferring one of these explanations to the other; still more difficult would it be to justify the use of one of them to the exclusion of the other.

Sympathetic Energy-Expenditure in the Interpretation of Psychogalvanic Results. The writer has already suggested an interpretation of the p.g.r. in terms of energy-expenditure of the sympathetic division of the autonomic nervous system, and the organs which it innervates,¹ (See p. 10, this paper.) It seems to him that the significance of the p.g.r. for this experiment and perhaps for psychology in general may most satisfactorily be expressed in terms of sympathetic energy-expenditure. This is, if anything, somewhat less vague than the other terms proposed. It expresses something that seems to underlie and be common to them. It is freer than the other terms from implications of qualitative distinctions which cannot be satisfactorily disentangled. It lends itself readily to quantitative description. Finally, it ties up the response with its probable physiological background.

How does the above interpretation apply to introspective results, and states of consciousness? The writer cannot refrain from a brief discussion—which is frankly speculative, but possibly clarifying—of this point.

Introspective Results as Related to Sympathetic Energy-Expenditure. In view of the functions controlled by the sympathetic one would expect its hyper-activity to have characteristic conscious accompaniments. One may reasonably go a step further and suppose that hyper-functioning of the sympathetic and its physiological concomitants may be experienced in consciousness either preponderantly as emotion or increased affective tone, or preponderantly as conation or impulsive striving; both, it seems, might be closely connected with sympathetic activity. Certainly both impulse and emotion are intimately bound up with primitive emergency situations, and one can hardly conceive of a conscious reaction to such a situation without some degree of both (viz., the impulse to immediate overt response, and a "stirred-up state of feeling").

The conscious experience might be determined by the particular kind of behavior patterns dominant during the sympathetic hyper-functioning. Perhaps conation would be the chief introspective concomitant if the behavior of the organism in meeting the emergency were smooth-functioning and uninhibited; whereas emotion or affective tone might be the predominant introspective correlate if there were intra-organic conflict be-

¹ Of course the writer is aware that the interpretation suggested above should be used only tentatively and provisionally. He presents it rather as a suggestion than as a theory. He has gone a step farther and been more explicit (perhaps on grounds which are too speculative) than Landis (23), who considers the response "a fairly certain means of demonstrating autonomic activity." However, for reasons outlined on p. 10 of this paper, the writer feels that the further suggestions he has made are at least a reasonable interpretation of the facts as now known.

tween various physiological patterns (e.g. mental conflict) or if any strong tendency toward reaction had to be inhibited from overt expression.

This may help to explain the fact that many experimenters have reported great difficulty on the part of their subjects in describing their mental processes in connection with psychogalvanic responses. Moreover if the writer's interpretation is correct, the attempts to establish the p.g.r. as essentially an indicator of any particular conscious process distinguished either in conventional psychological terminology or in that of the "man in the street" are probably futile. The writer is in agreement with Landis (23) on this point.

Interpretation of the Writer's Introspective Results. In view of the above, the writer feels that his own results in which *both* nervousness-excitement (emotion?) and effort-alertness (conation?) are consistently reported by psychologically naive subjects are quite in line with the general run of introspective psychogalvanic results. That no clearly defined leaning is shown toward either emotion or conation to the exclusion of the other seems to the writer of no particular significance, and to be probably simply a result of the particular experimental conditions.

Under other conditions or with a different type of subjects one might find preferences in favor of emotion, or vice-versa. But these preferences would not prove anything in regard to the essential psychological accompaniment of the p.g.r.

However, the writer would like to emphasize that the reports of his subjects unequivocally and consistently indicate that they "felt differently" at the critical points, where large psychogalvanic deflections occurred, than they did during the easy or unexciting portions of the experimental task. Introspective results, where obtained by other experimenters seem generally in agreement with this. There appear to be certain conscious components which accompany increase of psychogalvanic reactivity and others which do not.

"Feeling-Tension" as a Term for the Conscious Accompaniments of the P.G.R. The point is that no conventionally current name seems to fit these conscious accompaniments satisfactorily. If one must have a name, perhaps *tension*¹ or *feeling-tension*² would best fit the cases of high

¹ M. M. White (see p. 9, this paper) and A. A. Grünbaum (17), have used the word "tension," each in a somewhat different sense than that of the present writer, in connection with explanations of the psychogalvanic response.

² The opinion has been expressed, however, (see p. 38 this paper) that large p.g. reactions commonly occur when relaxation or relief suddenly takes place. Though the writer feels somewhat in doubt upon this point it seems to him quite likely that the p.g. deflections which occur when a tension situation is suddenly removed do not represent a relaxation of physiological processes, but rather a continuance of the reaction to the tension-stimuli, due to the inability of the organism to adapt itself at once to the sudden change in the situation. (See p. 38 this paper). It does

psychogalvanic reactivity, and *relaxation* the cases of low psychogalvanic reactivity, these terms being used in a sense somewhat analogous to the tension-relaxation component in Wundt's tri-dimensional theory of feeling, but with the understanding that as here used they are merely general descriptive terms for states of feeling characteristic of emergency situations, or the reverse.

not seem to the writer that there is any evidence of high p.g. reactivity occurring during calm or relaxed feeling states when these are clearly separated from tension situations.

CHAPTER V

SUMMARY AND INTERPRETATION

1. THE EXPERIMENTAL PROCEDURE

Psychogalvanic responses of twenty-four girls, all of them juniors or seniors in the School of Education of the University of Michigan, were obtained during a series of addition tests.

Besides a preliminary test consisting of twenty easy examples with no time limit, six different tests were given, each consisting of twenty examples. Three of the tests involved changes in the complexity (difficulty) of the material, with no time limit. The material of the other tests was of approximately the same complexity throughout, but changes were introduced in the amount of time allowed for different parts of the same test. Only one test was given at the same sitting. Each subject took three (and some subjects, four) tests besides the preliminary test.¹

The examples were presented consecutively on an exposure apparatus. Answers were given orally. The psychogalvanic response corresponding to each answer was recorded photographically by means of a modified form of the Wechsler Psychogalvanograph.

For each example of every test the corresponding mean galvanometer deflection (for the group of subjects) with standard deviation was obtained. With these data, comparisons were made of mean deflections and standard deviations accompanying the different experimental changes introduced in the tests. Similar but less extensive comparisons were made of the results of individual subjects. Rank-Difference correlations were obtained between measures of the galvanic responses of the same subjects on different tests. Rough comparisons were made between several measures of the arithmetic ability and personality traits of individual subjects, and their galvanic responses.

2. CONCLUSIONS

I. Effect of Abrupt Changes in Stimulus Situation²

(1.) The first two or three examples of all the writer's tests are accompanied by very large galvanometer deflections comparable with deflections at experimentally introduced critical points.

¹ A number of test results were invalid for one reason or another and had to be discarded, hence not all subjects are represented by as many as three tests in the final results.

² Conclusions headed 1, 2, 3 and 4 are all based on average results for the different tests. They are of course not invariably true of individual cases.

(2.) When all examples of a test are kept at approximately the same level of complexity and speed, no deflections of outstanding amplitude occur, except as explained above. There is a continuous tendency toward decrease in average amplitude of deflection from the beginning to the end of the test, but the rate of decrease is greater at the beginning.

(3.) Critical points, or points of abrupt increase in complexity or speed, are on the different tests invariably accompanied by a large increase in amplitude of deflection, as compared with the immediately preceding examples. Other things being equal, critical points near the beginning of the test are accompanied by larger deflections than critical points near the end.

(4.) Abrupt decreases in complexity or speed on the different tests are invariably accompanied by a decrease in amplitude of deflection, though these decreases are in no case great.

II. The Phenomenon of Adjustment Curves

(5.) Both the deflection curve following the initial examples of each test, and that following the initial example at the majority of other critical points, drop very rapidly even though the examples continue on the new high level of difficulty or speed. The curves consistently take a parabolic form with acceleration of the drop regularly decreasing after a series of three or four examples. The writer has called curves of this sort adjustment curves. It is suggested that these curves are accompanied by central nervous changes and indicate adaptation to the stimulus situation.

(6.) The adjustment curves tend to drop more rapidly and continuously in the speed tests than they do in the complexity tests.

(7.) Despite the adjustment curve tendency, deflections for all the difficult examples and for the majority of fast examples, regardless of position in the series, are larger than the mean deflection for the easy or slow examples (excluding the three initial examples of each test). Hence, although the sudden appearance of a more or less critical situation seems to be the main factor in causing large deflections in these experiments, a more continuous increase in the energy or tension-evoking character of the stimulus situation appears to be a contributory factor.

III. Objective Checks on the Results

(8.) Complexity and speed are objectively checked as factors of difficulty. There is quite a close and consistent relationship between increase in complexity of examples and number of incorrect answers by subjects; fast examples also result in a significantly greater number of incorrect answers than easy examples.

(9.) The muscular movement due to speaking seems to contribute only slightly, if at all, to the amplitude of the deflections.

IV. *Individual Results*

(10.) The individual deflection curves consistently show the same main tendencies as the average curves.

(11.) There is a fair correlation (about $+.50$) between average amplitude of deflections of the same subjects on different tests.

V. *Theoretical Assumptions*

The writer believes that there is a core of agreement among most investigators who have attempted a psychological interpretation of the p.g.r. and that this agreement may derive from the connection of the p.g. phenomenon with the sympathetic division of the autonomic nervous system and the influence of the latter upon behavior. The writer's own experimental results seem best interpreted from this viewpoint. It is suggested that the p.g.r. may be most satisfactorily interpreted as an indicator of increased sympathetic activity or of increased feeling-tension.

VI. *Significance of the Present Experiment*

The *fact* that amplitude of psychogalvanic reaction is consistently related to changes in speed and difficulty of one type of mental work seems quite clearly established by the present experiment.

In what significant ways may this fact be used? The problem can no longer be considered directly as one of measuring the effect of conation or emotion on mental output, but we can perhaps obtain definite knowledge of (a) the conditions under which increase in "sympathetic energy-expenditure" and/or increased "feeling-tension" typically occur in relation to mental work, and (b) the conditions under which increases in sympathetic energy-expenditure and/or increased feeling-tension help, hinder or are indifferent to efficient output in mental work.

The present experiment may be considered as a contribution to part *a* of the problem. The writer has made a few very tentative observations in regard to part *b*, but this must be considered almost wholly a subject for future investigation.

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Reviews and summaries of the literature are marked with an *.

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ADDENDUM

- * Landis, C. Electrical Phenomena of the Skin. *Psychol. Bull.*, 1932, 29, 693-752.

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